LUNAR CORING DRILL: GT LCD 85

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ABSTRACT

This is the design of a lunar core drill that is expected to operate safely in the lunar environment, to extract core samples from the ground of the moon with 3/4 of an inch in diameter. The instrument is to be mounted on a backhoe (also designed to work on the moon), and to be driven by a hydraulic motor. A detailed description of the various parts of this machine has been presented along with detailed drawings.

PROBLEM STATEMENT

BACKGROUND

There were many problems encounterred in the design of the lunar core drill with most created by the lunar environment. The temperature can range from 200 degrees farenheit to negative 200 degrees farenheit which is far from the conditions found on earth. There is also the problem of intense radiation on the moon caused by the lack of an ozone layer or similar atmospheric protection. Moreover the gravity on the moon is one sixth of that on earth, and thus it takes one sixth of the force required on earth to move an object. To complicate matters even more the lunar environment contains no air; a situation not encounterred on earth. When dealing with core drilling on the moon, another factor that must be taken into consideration is the ease of transportation to the moon and the ease of use on the moon. It costs a tremendous amount of money to send equipment to the moon so the less the weight the better. The less space occupied by the core drill package would be another step in the right direction. The ease of use is yet another important factor. The drill system must be easy to assemble, dismantle, and replace components. The more complicated the drill assembly the more problems possible, and on the moon there are no repair shops or parts warehouses.

PERFORMANCE OBJECTIVES

The main objective of the project was to design a lunar core drill able to drill vertically 50 ft. into the moon to obtain consolidated core samples having a radius of approximately 0.4225 in.

CONSTRAINTS

The environment constrains the lunar core drill in many respects. The quality of the hydraulic seals is of crucial importance. Any opening no matter how small will allow air to escape into the environment and the fluid will evaporate. The vacuum environment also prevents the ground up chips at the bit face from being flushed away by liquid means. As a result an alternate dust removal method had to be devised. Since the gravity on the moon is one sixth of the earth's the anchoring system was of the utmost importance. The system must be anchored or held solidly to the ground otherwise the thrust exerted by the hydraulic system will push the assembly off the ground and the cutting action will be reduced significantly. The high radiation count and wide temperature range in the lunar environment allows for only the least sensitve metals and synthetic rubbers to be used.

DETAILED DESCRIPTION

CORE BIT DESIGN

1. PURPOSE

The final bit design for the lunar core drill was a combination of the standard EWG size diamond core bit manufactured by Acker and the optimal design parameters discovered by NASA during their research in a simulated lunar environment. A considerable number of modifications were made on the standard drill bit design when taking into account the lunar environment. The two top priorities considered in the design process were the durability of the bit and the dust removal from the bit.

2. DIAMOND CLASSIFICATION

The selection process for the type of diamond to be used involved such factors as durability and cutting ability. For the standard bit, Acker uses AAA quality West African Boartz diamonds with octahedron or dodecahedron crystal structures with sizes ranging from 10/carat to 50/carat depending on the hardness of the rock being drilled through. However, NASA used AAAA quality Boartz diamonds in their experiments. AAAA quality diamonds are more uniform and of a higher quality than the AAA type and thus are less susceptible to failure under lunar or, for that matter, earvhly operatine colditions, The octahedrmn crystal structure was chosen over the dodecahedron structure because of its greater cutting ability although the lives of the stones are approximately the same. It has sharper edges for cutting rock and with the possible use of a microprocessor to control the penetration rate according to the cutting easg this crystal structure is preferred. The weight or the size selection of the diamonds must be made according to the hardness of the rock formation. In the simulated lunar environment that NASA created , iron rich basalt uas used because of the similarity of its properties to that of moon rock. The hardness of basalt lies between those of feldspar and quartz and according to the Acker catalogue the choice would be a diamond of 26/carat size. Along these lines NASA concluded that the 20/carat stones wer the best choice simply because they gave a better life than the larger 15/carat ones uhose shorter life was caused by the stone's planes and points tending to be more rounded than the smaller weight stones.

3. Diqmond Orientation and Pattern

When designing the drill bit diamond orientation and pattern the results from NASA's lunar coring simulation were heavily consulted. The two most important parameters set by the NASA operation in determining the bit's diamond orientation and pattern were an average diamond protrusion on the bit face of 0.010 in. and pattern of 31 complete line circles(a line circle is a radial row of diamonds) on the bit face. These two values affected the spacing between diamonds and the width of the dust removal channels on the face of the drill bit to be cast. The diamond protrusion of 0.010 in. was found by NASA to give the optimum bit life as was the 31 line circles. Given a protrusion of 0.210 in. for an octahedron the length of a side of the diamond at the bit face is 0.222 in. with a diagonal width of 0.0283 in. based on the geometry of the figure. In order to determine the number of diamonds in each line circle the thickness of the core bit obviously had to be taken into account, but perhaps more importantly the principle that the space between each adjacent diamond on the plane of the bit face whether" adially or circumferentially has to be less than the width of the diamond. Otherwise the matrix could contact on the rock and uin the bit. For the radial spacing of the diamonds the problem as solved as follows:

adial thickness of bit face = 0.1125 in.

width of diamond at bit face = 0.02 in.

number of diamonds able to fit = 0.3125 in./0.02 in. = 15.625

In other words there is room for 15 diamonds to fit in radially. However there must be some space for dust to flow so that it may reach a dust removal channel or be moved to the outside by centrifugal forces before reaching a channel. Any number of diamonds from eight to twelve would be adequate, but ften would allow for the best combination of dust removal and matrix safety. Therefore the radial distance betueen each diamond will be (0.1125 in. - 10(0.02in.)/9 = 0.0125 in.

In determining the angular spacing of line circles the same principle was taken into account, while assuming. for the time being, there was no 10 line circle stipulation (changes from 31 to 30 line circles for the ease of calculation). By reasoning that if the last two line circles were within 0.02 in. of each other (or 0.04 if measured from the centers of the diamonds, the angular spacing would be acceptable. The problem was solved as follows:

The last diamond on each line circle has its center located approximately (0.735 in. - 0.01 in.) = 0.725 in. away from the center od the bit face plane. Traveling along this newly created radius the next diamond center must be at most 0.04 in. away. Therefore the angular spacing of the line circles will be (0.04in./0.725in.)(180/PI)=3.16 degrees=theta. To have an easier figure to work with theta will be set equal to 3.0 degrees. At the innermost radius the diamonds will not touch even at this angle. (3)(PI/180)(0.4235in.)=spacing=0.0222in.

0.02 in. < 0.0222 in. < 0.04 in.

Now the bit will have 120 line circles which is far too many, but in the next section concerning the bit matrkx contour the number will be reduced to 30 with the unused area being reserved for the critically important dust removal channels.

The stones on the bit face were each given a negative rake angle of 4.5 degrees because according to the NASA experiment this angle was the optimum for bit life and cutting ability. The stones on the inner and outer radii are not involved in as an intense cutting process as those on the face, and therefore do not require any rake angle, but nonetheless perform vital functions. The diamonds on the inside shape the core diameter uhile those on the outside shape the wall of the hole. The diamonds on the inside and outside diameters are merely continuations of those on the face with their lines of centers running parallel to the centerline of the bit shaft.

4. Bit Matrix Contour

In designing the bit matrix contour the top priority was to have an efficient as possible dust removal system since nearly 80% of all the heat caused by drilling remains in the chips and these chips cannot simply be flushed away by liquid means. An excess amount of chips on the bit face cannot only cause melting of the bit but obstruct cutting of the rock formations. One possible method considered was to have a flow of pellets pushing the dust to the outside periphery, but there was a very limited amount of space to create such a system. Therefore the only seemingly acceptable dust removal system was to have channels in the face of the bit leading to the auger flights on the outside in a similar fashion to NASA's design. As stated earlier, NASA found 30 line circles to be approximately the most effective number to have. The goal was to have the widest dust removal channels possible at the smallest possible angle from the respective inner radius tangent. The final matrix face design as seen on sheet 11A provided an acceptable scheme for removing dust from the bit face and inside diameter. It provides a good combination of a small enough angle to allow easy chip flow to the outside utilizing centrifugal force, and a wide enough channel to allow large flows of dust to leave the face. The dust removal channels interrupt what would be the 90 remaining line circles giving the bit the 30 complete ones plus 40 additional incomplete ones. The 40 incomplete line circles are necessary to keep the surface of the bit not channeled through from being worn down by the grinding action of the rock chips. The depth of the channels were calculated using the depth of the auger flights machined into the core barrel. There are ten channels for dust removal leading to two auger flights in the fashion depicted on sheet 11 of the diamond core bit drawings. The dimensions and specifications of the entire matrix are given on sheets 11-11C.

The depth of the dust removal channels as seen on sheet 11 was calculated using the diameter of the bit, the diameter of the core barrel, and the depth of the auger flights. Since the auger flight depth is 0.05 in., the channels in the bit face must be deeper than 0.05 in. to make up for the extra 0.015 in. of radius the bit crown has opposed to the core barrel's. There must be a continuous channel changeover from the bit to the reaming shell and outer barrel. The depth of the dust removal channels is therefore 0.015 in. + 0.05 in. = 0.065 in.

CORE DUST REMOVAL

1. BACKGROUND INFORMATION

1.1. CORE DRILLING

Core drilling is the process of obtaining cylindrical soil samples for site preparation prior to building. There are three methods of core drilling: rotary, percussion, and rotary-percussion. Rotary drilling shears the rock with a rotating hollow cylindrical drill bit. The bit is attached to the driving motor by a hollow core barrel which contains the core sample. Percussion drilling is impact drilling. The core barrel and bit (drill string) are driven by a percussion mechanism which lifts and drops the drill string repeatedly to impact its way through the soil. Rotary-percussion drilling combines the methods of rotary and percussion drilling to penetrate the soil by impacting with a rotating bit.

1.2. CUTTINGS REMOVAL AND BIT COOLING

As the drill cuts, the cuttings which are produced are removed by flushing with water or air. The removal medium is pumped down the inner annulus of the core barrel, flows around the bit and up the outer annulus of the core barrel ~~(Figure 1)~~. This process serves two purposes: to remove the cuttings and to cool the bit. If the cuttings are not removed, the bit will eventually bind in the hole because the friction will become too great for the motor to turn the drill string. The flow of the removal medium in this case serves to transport the cuttings from the bottom of the hole to the surface. Also, the energy to fracture the rocks in the ground produces heat at the bit-rock interface, and, therefore, bit overheating becomes a problem. The flow of the removal medium around the bit serves to cool the bit by convection.

1.3. LUNAR PROBLEMS

However, because of the vacuum of the lunar environment, water and other gases would diffuse, and therefore become ineffective as a method for cuttings removal and heat dissipation. For the lunar environment, a system needs to be developed which will be able to remove the cuttings and dissipate the heat produced by a lunar core drilling operation.

2. PURPOSE

The purpose of this report is to propose a design which will solve the problems of cuttings removal and bit heating to permit core drilling on the lunar surface.

3. ALTERNATIVES CONSIDERED

3.1. SUSPENSION TRANSPORT

Suspension transport is the method of removing cuttings by means of a liquid or gas medium. In the lunar environment, liquids would be useless for cuttings removal because they would vaporize into the atmosphere and, therefore, not be able to transport the coring dust. However, a compressed gas with proper release around the bit may be able to remove the cuttings. This type of system would be similar to the systems now used on Earth, although it would require a complex manifold to properly release the compressed gas around the bit. Also, it would require storage tanks for the compressed gas. In general, gas storage tanks are heavy, and this extra weight certainly needs to be considered if it is to be transported to the Moon.

3.2. MECHANICAL TRANSPORT

Mechanical transport is a method of removing cuttings by continuous screw transport using helical flights (auger system). This means that the chips are channeled into a spiral flight and are lifted by the screw action of the rotating core barrel. Ideally, the volume flow rate of coring dust through the screw equals the production rate of cuttings by the bit. However, in actual practice, chips fall out between the auger and the hole wall so that the flights tend to recycle the cuttings. In this case, the volume flow rate of cuttings transported by the auger flights must be greater than the production rate at the bit. Mechanical transport is commonly used in ice core drilling which is similar to lunar drilling in that water flushing can not be used because the water would freeze in the hole. Therefore, this is a proven method which can be applied to lunar core drilling.

4. CONSTRAINTS

Our assignment was to obtain fifty foot core samples for site exploration on the Moon prior to building a lunar base. We were instructed to use the smallest standard diameter drilling equipment (bit, core barrel, and drill rods) to reduce the drilling power requirements and the total system weight.

5. PRELIMINARY DESIGN

Because of its simplicity, proven effectiveness, and comparitive light weight, I have chosen to use the auger system for our preliminary Lunar Core Drill design. This system will require the design of auger flights to transport the cuttings and a chip basket to contain the coring dust. The double tube core barrel is a presently available tool which can accomplish this task. The double tube core barrel is a device in which the outer barrel connects the motor to the drill bit and the inner barrel contains the cylindrical core sample. A bearing system (head assembly) separates the outer barrel from the inner barrel to keep the inner barrel from rotating, thereby producing a more distinguishable core. For our system, auger flights could be machined into the outer barrel, while the inner barrel could be modified to contain the core and the cuttings.

5.1. AUGER FLIGHT DESIGN

5.1.1. Cuttings Removal

The primary function of the auger system is to remove the cuttings produced by the drilling operation. Therefore, the auger flights must pick up the cuttings as they are produced by the bit and lift them to the surface of the hole or into a chip basket.

5.1.1.1. Auger Angle

The auger angle is the pitch of the auger flights, and it controls the speed at which the cuttings are lifted. A higher auger angle increases the rate which the cuttings move up the barrel, thereby increasing the volume flow rate of cuttings transported in the helical flights. However, it also makes it more difficult for the chips to enter the flights at the bit, and increases the power used to lift the cuttings. A lower auger angle, on the other hand, reduces the power required and makes the entry of the coring dust into the flights easier, although it also reduces the volume flow rate of the transported cuttings. Therefore, a compromise must be reached to reduce the power required and increase the ease of cuttings entry into the auger flights while still maintaining an adequate volume flow rate through the helical flights to keep up with the volume of cuttings produced by the bit.

5.1.1.2. Auger Flight Dimensions

The auger flight dimensions determine the volume flow rate of cuttings which can be transported for a given angular velocity and auger angle. As the auger flight depth and width increase, the cross sectional area also increases, thereby increasing the volume flow rate of the transported cuttings. However, there are limitations to the auger flight dimensions. If spirals are being added onto the outside of the core barrel, the outside diameter of the spiral helix can not exceed the inside diameter of the hole being produced or friction will result. Also, if auger flights are machined into the barrel, the inside diameter of the spiral helix can not be smaller than the inside diameter of the core barrel or you will ruin the barrel. For these reasons, consideration of auger flight dimensions is necessary in preventing later problems.

5.1.2. Bit Cooling

The energy to shear the rock in rotary drilling produces heat at the rock-bit interface. This heat is then transferred to the cuttings, the rock, and the bit. Since there is no convective heat transfer from the lunar environment, bit overheating will be a problem. As the bit temperature increases, the steel bit matrix will begin to melt, causing deformation of the bit and a reduced penetration rate. Then, if the bit temperature continues to increase, the diamonds will deform and dull, stopping the drilling. Experimentation done by the Martin-Marietta Corporation (ref.2) concluded that eighty percent of the heat generated is transferred to the chips, part of the heat goes to the rocks, and a small portion of the heat is transferred to the bit. Therefore, if the cuttings can be removed effectively by the auger system, dry core drilling can be accomplished.

5.2. CHIP BASKET DESIGN

Because of our fifty foot drilling depth requirement, it is necessary to propose a chip basket design to prevent transporting the cuttings to the hole surface when drilling depths exceed ten feet. I propose to modify the inner barrel of a double tube core barrel to contain the coring dust as well as the core sample. This would require division of the inner barrel by a plate separator to prevent the cuttings from mixing with the core sample, and an entry section through which the coring dust could enter the inner barrel from the helical flights on the outer rotating barrel.

5.2.1. Chip Basket Separator

The chip basket separator will be a circular flat plate approximately 1/4 inch thick and the same diameter as the inside diameter of the inner core barrel. This flat plate will be welded on the inside of the inner barrel just above the core sample section to prevent mixing of the cuttings with the core sample.

5.2.2. Chip Basket Entry

Entry of the cuttings into the inner barrel assembly will be through a hole in the outer barrel and a vaned section in the inner barrel ~~(see Figure 1)~~. This entry section would contain four steel rods, equally separated and welded around the inner barrel section, to permit easy cuttings entry, and would be located at the same horizontal level as the holes which are drilled in the outer barrel at the end of the auger flights. This will allow the cuttings to flow from the outer barrel auger flight through the hole and the vaned entry section into the inner core barrel.

HYDRAULIC SYSTEMS

1 INTRODUCTION

1.1 BACKGRUOND

In considering types of prime movers for the lunar coring drill, two basic systems were analyzed: electro-mechanical, and hydraulic. The electro-mechanical systems have two major advantages; they are easily controlled and easily instrumented. Batteries and fuel cells are the only electrical power supplies feasible for lunar use. Solar-electric converters are not feasible, due to their fragile nature and size requirements for sufficient output. In order to operate the drill for eight hours, a two-thousand five-hundred pound(2500 lb) batery or a twenty pound(20 lb) fuel cell, which must be recharged twice during operation, needs to be integrated into the system. Power supply, however, isn't the only obstical presented by this type of system. The mechanical drive, be it rack and pinion or differential gear, posesses substantial wear potential and friction. Convential lubricants cannot be utilized to fight friction in a lunar environment because of vacuum vaporization.

In comparison, however, hydraulic drives offer minimum mechanical wear and friction. Hydraulics presents a whole new area of problems, though. Two outstanding ones are:

1) fluid containment
2) heat disipation

Vaporization of hydraulic fluid at the seal-actuator interface, elliminates the use of convential seals. Adequate fluid containment, however, can be achieved using advanced polyimide and molecular seals. Since there is no convection in the lunar environment, heat must ultimately be radiated away. Conducting heat from the fluid resevior(acting as system heat sink), to the vehicle frame, for radiative heat transfer, allows for sufficient heat dissipation from the hydraulic fluid.

A hydraulic system was ultimately selected to serve as the prime mover in the lunar coring drill. Hydraulics offer increased durrability over electro-mechanical systems and can be modified readily for lunar use. As well as its engineering advantages, a hydraulic system is also more economically desirable.

2 MOTOR CHOICE

A variable displacement axial piston type hydraulic motor was chosen for use as the rotary actuator in the lunar coring drill. An axial piston motor has less slippage, and hence more efficiency, than either vane or gear type hydraulic motors. Higher efficiencies are always desirable in any system but more so for lunar systems. Delivering more power from the hydraulic motor to the drill string decreases the amount of energy dissipated as heat to the hydraulic fluid. The heat generated, however, does need to br dissipated. Since, in a vacuum, heat can only be radiated, the generated heat should be kept to a minimum.

2.1 MOTOR DISCRIPTION

Shaft rotation in a variable displacement motor depends on a pressure gradient. The system consists of a rotor which connects directly to the output shaft. Bores, located in a prescribed anulus, are machined into the rotor. Pistons, located in the bores, slide on a tilted camplate.

The pressure gradient, created by a pump, causes the pistons to reciprocate and a flow to be induced. For reciprocation to occur, the rotor must spin and, hence, the output shaft must also spin.

2.2 MOTOR PARAMETER SPECIFICATION

Table 1 shows the necessary requirements that must be met by the hydraulic motor.

Q	23.42	in/s
T	800.00	in-lb
N	650.00	rpm
P	2500.00	psi
p	8.87	Hp

Q - flow rate N - speed p - power
T - torque P - pressure

Table 1 - motor parameters

These parameters were calculated with a ninety-three percent(93%) efficiency assumed for each component of the system. A complete torque and motor parameter analysis may be found in Appendix A.

3 HYDRAULIC CYLINDER

The cylinder lift force is determined by: the weight of the drill string, weight of the motor, and in-hole friction. The force required by the drill string weight is two-hundred sixty pounds(260 lb). The force due to the motor weight and in-hole friction, however, must also be included in this analysis. In-hole friction, during retraction, is estimated to be fifty pounds(50 lb). The terrestrial weight of the motor and mount is approximatly two-hundred pounds(200 lb), which places the lunar weight at around thirty-four pounds(34 lb). Therefore, with adequate safety factors included, the total lift force becomes one-thousand five pounds(1005 lb). Drilling, on the other hand, requires a one-thousand pound(1000 lb) push force. A thorough analysis of hydraulic cylinder force parameters can be found in Appendix B.

3.1 CYLINDER SIZING

From the hydraulic cylinder force information given above, the size of the bore and rod diameters can be determined. The bore diameter is obtained from the definition of pressure.

$$P = F_{down}/A \quad \text{and} \quad A = \pi d_{bore}^2/4$$

Therefore:

$$d = \sqrt{4F_{down}/P\pi}$$

$$d = \sqrt{4(1000\ \text{lb})/\pi(2600\ \text{psi})} = 0.7\ \text{in}$$

Assume a rod diameter of 0.5 in . The annulus area, then, is the bore area minus the rod cross-sectional area.

$$A_{bore} = \pi r_{bore}^2 = \pi(0.35\ \text{in})^2 = 0.3848\ \text{in}^2$$
$$A_{rod} = \pi r_{rod}^2 = \pi(0.25\ \text{in}) = 0.1983\ \text{in}^2$$
$$A_{ann} = A_{bore} - A_{rod} = 0.3848\ \text{in}^2 - 0.1983\ \text{in}^2$$
$$= 0.1865\ \text{in}^2$$

The annular area must now be checked to see if it is large enough to lift the required load.

$$0.1983\ \text{in}^2 > 1005\ \text{lb}/\ 2600\ \text{psi} = 0.3865\ \text{in}^2$$

As is seen from this result, the bore area must be increased to supply enough annular area to lift the load.

Let $d_{bore} = 1.0$ in
Then, $A_{bore} = \pi r_{bore}^2 = \pi(0.5 \text{ in})^2 = 0.7854 \text{ in}^2$
And, $A_{Ann} = 0.5871 \text{ in}^2$

Testing again:

$$0.5871 \text{ in}^2 > 1005 \text{ lb} / 2600 \text{ psi} = 0.3865 \text{ in}^2$$

This shows that a bore diameter of one inch(1.0 in) gives sufficient annular area.

3.2 COLUMN STABILITY

The hydraulic cylinder rod, when fully extended, can be modelled as a clamped-clamped column. Being so thin, the critical buckling load of the rod must be determined to see if failure is possible under loaded conditions. The critical buckling load for a clamped-clamped column is given by the relation:

$$P_{cr} = \pi 4IE/L^2$$

E = 30E6 psi   I = 0.0031 in^4 L = 54.0 in

P = 1260 lb

A margin of safety of two(2.0) is recommended for this application. that is, if the rod is to be laoded at one-thousand pounds(1000 lb), it must be capable of withstanding two-thousand pounds(2000 lb). From above, a half inch(0.5 in) diameter does not meet this requirement.

Let, $d_{rod} = 0.75$ in
Then, $P_{cr} = 2008$ lb

This diameter is acceptable. However, the annular area must be rechecked.

$$A_{rod} = \pi r_{rod}^2 = \pi (0.375\ in)^2 = 0.4418\ in^2$$
$$A_{Ann} = A_{bore} - A_{rod} = 0.7854\ in^2 - 0.4418\ in^2$$
$$= 0.3436\ in^2$$

This is unacceptable, therefore, let $d_{bore} = 1.2$ in .

$$A_{bore} = \pi r_{bore}^2 = \pi (0.6\ in)^2 = 1.131\ in^2$$
$$A_{Ann} = A_{bore} - A_{rod} = 1.131\ in^2 - 0.4418\ in^2$$
$$= 0.6892\ in^2$$

These dimensions: $d_{rod} = 0.75$ in, and $d_{bore} = 1.2$ in, now meet the requirements.

The commercial hydraulic cylinder that meets these criteria is the Lynair Inc. number H-1.2-A-3-1-54-0.75-S . The ordering scheme follows this form: Model-Bore Size-Mounting Style(foot mount)- Type of Cushioning(cap end only)-Rod End Style(full male) -Stroke Length-Rod Diameter-Port Location(same side as mount). The hydraulic cylinder should be equipped with a Chevron polyimide vacuum actuator seal. A sketch of the hydraulic cylinder is shown in figure 2.

4 FLUID CONTROL

It is desired that this system posess the ability to be attached and disconnected quickly from the main operating vehicle. To acomplish this, the design requires one input and one output flow line to the system. The two work producing fluidic components(hydraulic cylinder, hydraulic motor) must be supplied by this one input. Therefore, the input is directed into a flow divider. A Prince Hydraulics model RD 200(4:1) proportional flow divider can preform thes task.

4.1 FLOW DIVISION

The RD 200(4:1) proportional flow divider will divide the flow of one pump into two equal flows, regardless of the load variations on each stream. The input flow can change and the proportional flow divider will divide the flow equally. The unequal flow ratio is required because the flow rate in the hydraulic motor is approximately four times greater than that in the hydraulic cylinder. Flow through the divider is in one direction only. The outlet flow from each component is to be combined using a Y shaped flow combiner. A Snap-Tite Inc. model FSS40FT25NST Siamese fitting is acceptable for this pourpose. However, The Fitting must be scalled down to a one inch(1.0 in) output port and two one half inch(0.5 in) input ports. A device such as this would have a model number FSS1FT0.5NST according to the Snap-Tite Inc. ordering format.

4.2 CONTROL VALVES

The flow from each line of the proportional flow divider must be sent in two different directions. That is, to the rod and cap end of the hydraulic cylinder or to the high and low pressure ports of the hydraulic motor. The location of fluid supply will change depending on which direction the component is acting. A three-way valve directs the flow in this manner. The Prince Hydraulics model RD 2100 type T3 valve was selected for this application. This valve can power a hydraulic cylinder or hydraulic motor in both directions. In neutral, the work ports are blocked and the pressure port is open to tank. A summary of the RD 2100 type T3's characteristics is shown below in Table 2.

Port Size - 0.5 in inlet, outlet, and work ports
Spool Type - T3(3 way/open center)
Relief Type - direct type ball/spring relief
rated: 2800 psi for cylinder
2500 psi for motor
Load Check
Option - 1(load check installed)
Spool Attachment - 3 position spring center to neutral
Inlet - A(standard location)
Outlet - 1(standard location)

Table 2: RD 2100 T3 valve characteristics

4.3 PRESSURE GAUGES

The astronaut/operator needs some feedback on how the drilling operation is progressing. In terrestrial operation, the operator listens to the drill to tell if he is pushing it too hard or not hard enough. The hearing impairment, a lunar environment presents to the astronaut/operator, prevents him from listening to the drilling. To supply him with information, pressure gauges are placed at the outlet ports of the directional control valves for the hydraulic cylinder and hydraulic motor. These valves should be calibrated to red line at 2600 psi(hydraulic cylinder) and 2350 psi(hydraulic motor). A Templeton, Kenly & Co. gauge number 18900 with range 0 - 5000 psi and face dial diameter of 4.5 in is adequate for this job. This gauge requires an adapter, number 18976.

4.3 ACTUATOR SEALS

In our hydraulic cylinder system, we decide to use same actuator seals that in "NASA 1971 Space Shuttle Study" they designed. As you see Drawing 2-2-1, the approach to the high temperature actuator seal problem is the use of advanced polymers such as polyimides in chevron configurations with needed sealing force provided by pressure and metal springs.

According to their data, such designs have been successful under severe duty cycles to 500 F. In simulated aircraft fight cycle experiments at 500 F sealing a 4000 psi silicone fluid from atmosphere, the leakage rate for over 1000 hours of operation was less than 0.02 cc per hour. Also lubrication studies in vacuum show polymides to have excellent self-lubricating properties and have no measurable deterioration in vacuum until temperatures of about 700 F are reached.

4.5 ROTATING SHAFT SEALS

Like actuator seals, we are going to use the same rotating shaft seals that in "NASA 1971 Space Shuttle studies" they designed for the hydrauric motor. (shown Drawing 2-1-2A) This design utilizes a spiral groove radially outward pumping face seal with interface liquid feed to remove heat generated in share of the thin (100 to 200 microinch). Further, a helical groove molecular flow vapor seal with low surface energy barrier films is provided to contain leakage past the spiral liquid seal. (see Drawing 2-1-2B)

According to "NASA 1971 Space Shuttle Studies", the spiral groove concept was used to provide a no leakage seal for liquid sodium and oil and has been in corporated in recent experimental mainshaft seals for aircraft. Studies of a rotating helical molecular flow seal combined with a visco seal for organic fluids (4P3E polyphenyl ether) at modest pressures gave leakage rates vacuum (10 torr) of 0.7 to 2.6 kilograms in 10000 hours.

4.6 HOSE, FITTINGS, ASSEMBLIES

Hydaulic hose has a finite life and factors which will reduce hose life are;

(1) Flexing the hoose to less than the specified minimum bend radius.

(2) Twisting, pulling, kinking, crushing or abroading the hose.

(3) Operating above or below the hose operating temperature range.

(4) Exposing the hose to surge pressures above the operating the maximum operating pressure.

For our hydraulic system, hose should stand internal pressure under 2750 psi. We will use 'AEROQUIP CORP. High Pressure/ Hose, Fitting, Assemblies No. 680-8-L and MS28759-8-L.
Pressure/ Hose,3Ritting, Assemblies No. 680-8-L and MS28759-8-L.
3N

Parts List: Hydraulic Components

DRAWING	QUNTITY	ITEM #	PART #	DISCRIPTION
2	1	1	Lynair Inc. H-1.2-a-3-1-54-0.75-s	Hydraulic Cylinder
	1	2	Special	Cylinder Rod-Motor /Frame Mount Adapter
	1	3	Special	Motor/ Frame Mount
	2	4	Prince Hydraulics RD 2100 T3	Direction Control Valve
	1	5	Prince Hydraulics RD 200(4:1)	Propor- tional Flow Divider
	8	6	Aeroquip Corp. Hose 680-8-L	Hydraulic Hose
	1	7	Snap-Tite, Inc. FSS1FT0.5NST	Flow Combiner
	2	8	Templeton, Kenly & Co. # 18900	Pressure Gauge
	2	9	Templeton, Kenly & Co. # 18976	Pressure Gauge Adapter
	1	10	Sunstrand	Hydraulic Motor
2-3	1	1	Special	Actuator Seal
2-2	1	1	Special	Frame Struts
	1	2	Special	Frame Collar
2-4	1	1	Special	Adapter Housing
	1	2	Special	Clip Bar

1	3	Special	Retainer Spring
1	4	Special	Pivot Pin

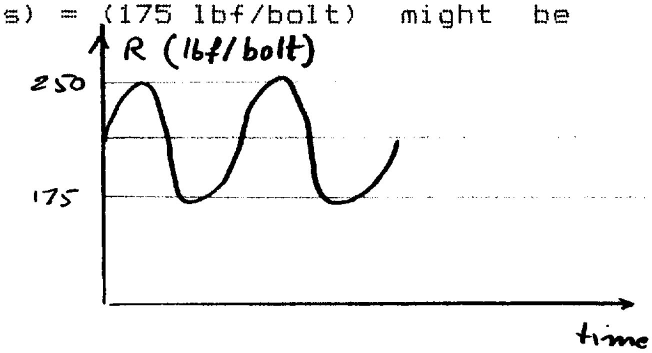
FRAME DESIGN

1. Anchor Design

The penetration force needed is approximately 700 lbf which if we neglect the weight of the drill, would cause a reaction shear force of 700 lbf distributed on four bolts.

Design of the type and size of the bolts.

Assume that during the operation, an additional fluctuating reaction of about (300 lbf/4 bolts) = (175 lbf/bolt) might be caused due to vibration.



Then the loading diagram would be that of figure .choosing a factor of safety n=2,the maximum shear stress on the bolt ,

$S=(n.r)/a =(2*250)/((\ \ /4)*d^2)$

Where d is the nominal diameter of the bolt.

Using a bolt material with S_{ut} = S_{uc} = 115 ksi,and using thedistortion energy theory of failure,we get:

$S_{max} = .577\ S_{ut}$

$= .577 * 115 = 66.35$ ksi

Using a fatigue strength reduction factor K_f for cut threads and

SAE grade from 4 to 8 : K = 3.8 which also accounts for surface finish factor,size factor and stress concentration factor,also using 50 % reliability.

Ignoring temperature and miscellaneous effect:

$$Se = 66.35/3.5 = 17.46 \text{ Ksi}$$

Equating (1) and (2)

$$2000/d = 17460$$

$$d = 0.2$$

in which is the minimal size for n=2 so to be on the safe side use d=0.3 in use SAE Grade 4 Bolt, 0.3 in diameter(Nominal)

Proof strength of 65 Ksi

Tensile strength of 115 Ksi

Yield strength of 100 Ksi

Hardness between C 22 and C 32 (Rockwell)

Medium carbon cold drawn steel

At = 0.045 in

To be conservative in our design we can use either larger bolt diameter or more than 4 bolts however larger number of bolts may yield a better load distribution which also helps distributing the vibrational stress.

2. Implement Interface Movement

Levelling the drill to operate vertically is a task achieved by hydraulic cylinders acting on the base of the drill; attached to the frame of the backhoe as shown in Figures A and B. The levelling mechanisms shown in Figure A cylinders 1, 2, 3, 4, and 5 account for rotating the drill about the z-axis and the y-axis.

Cylinders 1, 2, and 3 would control the required position with respect to the z-axis, and the two cylinders, number 4 and number 5 (symmetric to number 4 with respect to the x-y plane, not shown to simplify the drawing) would control the required position with respect to the y-axis. As far as the levelling around the x-axis is concerned, this should be accomplished by an implementary design on the body of the backhoe as shown in Figure 3. However this design is necessary for the backhoe to be able to assume that the drill is anchored to a rigid body with respect to the ground, which is necessary for the stability of the system when the drill is operating. With this additional feature we can acquire a levelling control around the x-axis within a narrow tolerance, which is also large enough to put the drill in a vertical position.

OPERATING INSTRUCTIONS

DRILL STRING ASSEMBLY AND DISASSEMBLY

To drill 0-5 feet (assembly):

1. Couple preassembled drill string head to motor.

Drill 5 feet, then to obtain core (disassembly):

1. Retract motor to upper limit position.
2. Unscrew head assembly from motor.
3. Unscrew outer core barrel from head assembly.
4. Pull out head assembly still attached to inner core

barrel.

5. Unscrew core lifter case from inner core barrel.
6. Slide core out of inner barrel.
7. Reattach core lifter case to inner core barrel.
8. Unscrew inner core barrel from head assembly.

To drill 5-10 feet (assembly):

1. Screw second preassembled outer core barrel to first outer core barrel (in ground).
2. Couple first inner core barrel to second preassembled inner core barrel.
3. Attach inner core barrel assembly to head assembly.
4. Insert inner core barrel string into assembled outer core barrel string.
5. Attach head assembly to outer core barrel string.
6. Attach head assembly to motor.

Drill 5 feet, then to obtain core (disassembly):

1. Retract motor to upper limit position.
2. Unscrew head assembly from motor.
3. Unscrew head assembly from outer core barrel.
4. Pull out head assembly still attached to inner core barrel string.
5. Unscrew core lifter case from bottom inner core barrel.
6. Slide out core from lower inner core barel.
7. Reattach core lifter case to bottom inner core barrel.
8. Unscrew inner core barrel string from head assembly.

To drill 10-15 feet (assembly):

1. Attach third preassembled outer core barrel to outer core barrel string (in ground).
2. Couple third vaned inner core barrel to top of inner core barrel string.
3. Attach head assembly to inner core barrel string.
4. Place inner core barrel string into outer core barrel string.
5. Attach head assembly to outer core barrel string.
6. Attach head assembly to motor.

Drill 5 feet, then to obtain core (disassembly):

1. Retract motor to upper limit.
2. Unscrew head assembly from motor.
3. Unscrew head assembly from outer core barrel.
4. Pull out head assembly still attached to inner core barrel string.
5. Unscrew core lifter case from bottom inner core barrel.
6. Slide out core.
7. Reattach core lifter case to bottom inner core barrel.
8. Unscrew inner core barrel string from head assembly.
9. Dump cuttings from upper two core barrels.
10. Attach head assembly to inner core barrel string.

To drill 15-50 feet (assembly):

1. Place inner core barrel string into outer core barrel string.
2. Attach head assembly to outer core barrel string.
3. Attach drill rod (5 ft.) to head assembly.

4. Attach drill rod sections until reach motor level.

5. Attach last drill rod to motor.

Drill 5 feet, then to obtain core (disassembly):

1. Retract motor to upper limit position.

2. Unscrew drill rod from motor.

3. Uncouple drill rod sections until reach the head assembly.

4. Uncouple last drill rod from head assembly, then repeat steps 3-10 for disassembly after 15 feet, and continue.

CONCLUSIONS & RECOMMENDATIONS

This report proposes a coring dust removal system for the lunar core drill being developed for NASA. This system will include auger flights to transport the cuttings produced and a chip basket to contain the coring dust when drilling depths exceed ten feet. I will use a double tube core barrel to accomplish these tasks. The auger flights will consist of grooves machined in the outer barrel, and the chip basket will be a modified inner barrel with a vaned entry section to allow the coring dust to enter and a flat plate separator to separate the cuttings from the coring sample.

After my preliminary design work, I have recognized three areas which will require further consideration: a wireline system to ease removal of the inner core barrel and chip basket, a bayonet mounting system for proper alignment of the auger flights, and a drilling duty cycle to allow the bit to cool by conduction to the lunar subsurface. Because of the difficulty which may be encountered assembling and disassembling the drill string at deep drilling depths, a wireline system needs to be considered which will reduce the wear on the outer core barrel and ease removal of the inner core barrel assembly. Also, a bayonet mounting system, similar to those used for 35mm camera lenses, would be an effective method for proper alignment of the auger flights on the different drill sections. Finally, since the estimated temperature of the lunar subsurface is 235 K at depths below thirty inches, a drilling duty cycle consisting of intermittent periods of drilling and cooling could prove to be an effective method to solve the problem of bit overheating.

Cooling the bit is still a main problem for its durability. Since convective cooling is out of the question because of operation in a high vacuum environment, we are left with two other solutions.

1) An internal cooling fluid cycle passing through drilled grooves in the core barrel wall. However, this solution is impractical because of the difficulties in manufacturing and in getting rid of the heat in a vacuum environment up on the surface, once the heat is extracted from the bit

2) Another solution is to rely on the radiation and conduction modes of heat transfer by feeding bit temperature information into a microprocessor attatched to the frame, which

would be programed to shut down operation once a prescribed temperature is reached. Then let the bit coll through conduction and radiation at the bit-rock interface. An information flow diagram is shown in figure C. However, to avoid the difficulties encountered in constructing this system, the microprocessor can be programed to shut down drilling after a prescribed penetration is reached. This program should be based on laboratory test measurement.

One possible recommendation would be to search for a less expensive core bit. The processes involved in making the desired core will be extremely expensive to manufacture and the materials, including the alloy and the diamonds used, do not come cheap either. Perhaps some sort of impregnated diamond bit should be researched more heavily. Although the current design has premium cutting ability and durability, an attempt at a less expensive bit might be worthwhile especially if cost is of great importance.

The speed and efficience of the entire drilling process depends soley upon the astronaut/operator. The astronaut/operator, on the ether hand, relies upon information received from the pressure gauges. To ensure accurate gauge readings and subsequent valve actuation, a microprocessor can be installed on the drill. The microprocessor will work by: 1) receiving pressure information from the pressure transducers located at the hydraulic cylinder and hydraulic motor high pressure ports; 2) comparing the incoming pressure data to critical(somewhat below red line) values stored in the microprocessor's memory; 3) if the pressure exceeds the critical value, the microprocessor will send a signal to the valve solenoid actuator, thus restoring the pressure to its optimal value. However, the microprocessor is not limited to only controlling system pressure. It may also be integrated into the system as a temperature monitoring device and/or with modification, a frame vibration and alignment sensor.

BIBLIOGRAPHY

Crouch, Donald S. Final Report for Lunar Rock Coring Device Design Study, Martin-Marietta Company for NASA, 1965 (N66-15364).

Herbert, Stan "Diamond Sawing- a developing technique." Civil Engineering (London), September, 1984.

Schmidt, R.L. "Developing A Lunar Drill: A 1969 Status Report." Bureau of Mines, Twin Cities Mining Research Center, Minneapolis, Minnesota. Proceedings of the Seventh Annual Working Group on Extraterrestrial Resources (NASA), 1970.

Splettstoesser, John F. Ice Core Drilling University of Nebrasksa Press, Lincoln and London, 1976.

Summary of Moderate Depth Lunar Drill Development Program (Final Report). Westinghouse Defense and Electronics System Center for NASA, June, 1972 (N72-27526).

Acker, W.L.,Basic Procedures for Soil Sampling and Core Drilling, Acker Drill Co. Inc. 1974, p. 246.

W.L. Acker III, Basic Procedures for Soil Sampling and Core Drilling, Acker Drill Co., Ackron, OH, copyright 1974

Gumenskii and Komarov, Soil Drilling by Vibration, Consultants Bureau, New York, NY, copyright 1961

Gene Anderson, Coring and Core Analysis Handbook, Petroleum Publishing Company, Tulsa, OK, copyright 1975

J. Korn, Hydrostatic Transmission Systems, Intertext Books, London, copyright 1969

Werner G. Holzbock, Hydraulic Power and Equipment, Industrial Press Inc., New York, NY, copyright 1968

Raymond P. Lambeck, Hydraulic Pumps and Motors, Marcel Dekker, Inc., New York, NY, copyright 1983

Stewart and Storer, ABC's of Fluid Power, Howard W. Sams & Co., Inc., Indianapolis, IN, copyright 1966

Roger E. Hatton, Introduction to Hydraulic Fluids, Reinhold Publishing Corporation, New York, NY, copyright 1962

APPENDIX A

The estimated load necessary to cut hard rock is:

$$F_{down} = 500 \text{ lb}$$

The cutting load can be expressed as:

$$F_{cut} = 2 \times F_{down} = 2(500 \text{ lb}) = 1000 \text{ lb}$$

Friction results from cutting and from wall-drill string scraping. The wall-drill string friction is estimated to be $F_{wall\ fric}$ = 100 lb.

$$F_{fric} = F_{down}\mu = 500 \text{ lb } (0.5) = 250 \text{ lb}$$

0.5 = coefficient of sliding friction(μ)

The total perriferial force is the sum of the frictional forces and the cutting force.

$$\begin{aligned} F_{TOT} &= F_{fric} + F_{wall\ fric} + F_{cut} \\ &= 250 \text{ lb} + 100 \text{ lb} + 1000 \text{ lb} \\ &= 1350 \text{ lb} \end{aligned}$$

The torque required for drilling can now be determined.

$$T_{force} = F_{TOT} \times r_{Avg}$$

where, r_{Avg} = average bit radius

$$\begin{aligned} T_{force} &= 1350 \text{ lb } (0.5788 \text{ in}) \\ &= 780 \text{ in-lb} \end{aligned}$$

The inertial torque must also be accounted for.

$$T_{in} = mr_{Avg}^2$$

where, $m = \rho AL = (0.2703 \text{ lb}/\text{in}^3)(0.2977 \text{ in}^2)(600 \text{ in})$
$= 48\ 27.1b_m$

Therefore, $T_{in} = (48.27 \text{ lb})(0.5788 \text{ in}) = 11.2$ in-lb

The total torque is the sum of the cutting torque and the inertial torque.

$$T_{TOT} = T_{force} + T_{in}$$
$$= 780 \text{ in-lb} + 11.2 \text{ in-lb}$$
$$= 800 \text{ in-lb}$$

Using the torque information above, the other motor parameters can be calculated.

Estimated output speed(N) to be 0 - 650 rpm

The power expended can be expressed as:

$$P_{OUT} = T_{TOT} \times N/63000$$
$$= 800 \text{ in-lb} \times 650 \text{ rpm}/63000$$
$$= 8.25 \text{ Hp}$$

Also, $P_{OUT} = P \times Q/6600 = 8.25$ Hp
$= 2500 \text{ psi} \times Q/6600$

Therefore, $Q = 21.78 \text{ in}^3/\text{s}$

The estimated efficiency of all fluidic components is assumed to be ninety-three percent(93%). Thus, the parameters must be corrected for this rating.

$$Q = 21.78 \text{ in}^3/\text{s} / 0.93 = 23.42 \text{ in}^3/\text{s}$$
$$p = 8.25 \text{ Hp}/0.93 = 8.87 \text{ Hp}$$

The motor parameters are summarized below, in Table A.1.

$Q = 23.42 \text{ in}^3/\text{s}$	$N = 650$ rpm	$P = 2500$ psi
$T = 800$ in-lb	$P_{OUT} = 8.87$ Hp	

APPENDIX B

This appendix summarizes the calculation of drill-string weight and inertial lift force. The total force(F) required by drill-string weight and inertia can be expressed as:

$$F_w = ma + w$$

m - mass
a - acceleration
w - weight

The mass is given by:

$$m = \rho AL$$
$$= 0.2703 \text{ lb /in}^3 (0.277 \text{ in}^2)(600 \text{ in})$$
$$= 48.27 \text{ lb}_m$$

ρ - density
A - cross-sectional area
L - length

The weight is given by:

$$w = mg$$
$$= 48.27\text{lb } (5.367 \text{ ft/s })$$
$$= 259 \text{ lb}$$

g - lunar gravitation
$g = g/6 = 32.2 \text{ ft/s}^2/6$
$= 5.367 \text{ ft/s}^2$

The acceleration is given by:

$$a = v^2/2s$$

v - velocity
s - stroke distance

The expected velocity is ten feet per minute(10 fpm). The stroke distance is four and a half feet(4.5 ft).

Therefore, $a = ((10 \text{ fpm})(1 \text{ min}/60 \text{ sec}))^2/2(4.5 \text{ ft})$
$= 0.0031 \text{ ft/s}^2$

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The necessary elements required to determine the force needed to overcome drill-string weight and inertia are now available.

$$F_w = ma + w$$
$$= 48.27 \text{ lb } (0.0031 \text{ ft/s }) + 259 \text{ lb}$$
$$= 260 \text{ lb}$$

Motor weight and in-hole friction must be included in this analysis as other forces(F_{oth}). The motor is estimated to be fifty pounds(50 lb) and the in-hole friction is estimated to be two - hundred pounds(200 lb).

Therefore:

$$F_{oth} = 50 \text{ lb} + (200 \text{ lb} / 32.2 \text{ ft/s}^2)(5.367 \text{ ft/s}^2)$$
$$= 75 \text{ lb}$$

The total lifting force then becomes:

$$F_{TOT} = F_w + F_{oth}$$
$$= 260 \text{ lb} + 75 \text{ lb}$$
$$= 335 \text{ lb}$$

A safety factor of three(3) must be incorporated in this value. Hence:

$$F_{TOT} = 335 \text{ lb}(3)$$
$$= 1005 \text{ lb}$$

The force required to push the drill string durring coring is five-hundred puonds(500 lb). The assumptions made in estimating this value warent a safety factor of two(2). Therefore the push force is:

$$F_{down} = 500 \text{ lb}(2) = 1000 \text{ lb}$$

APPENDIX C

Volume Flow Rate Calculations:

The volume flow rate of the cuttings produced by drilling is:

$$VP = HA * P$$

where VP is the volume produced per minute,
HA is the hole area, and
P is the penetration rate.

The hole area is:

$$HA = \pi * (H^2 - C^2) / 4$$

where H is the hole diameter, and
C is the core diameter.

For "E" size drilling equipment,
H = 1.5 inches, and
C = 0.8125 inches.

Therefore, HA = 1.25 in^2.

The maximum penetration rate for the Lunar Core Drill is 4 inches per minute.

$$\underline{VP = 5\ in^3/min}$$

The volume flow rate of cuttings removed by the auger flights is:

$$VR = GA * GL * RPM$$

where VR is the volume flow rate of cuttings removed,
GA is the auger flight groove area,
GL is the length of the auger flights per revolution, and
RPM is the angular velocity ofthe drill string.

The groove area is:

$$GA = GD * GW$$

where GD is the groove depth, and
GW is the groove width.

If I assume GD = 0.05 inch and
GW = 0.1875 inch,

then GA = 0.0094 in^2.

The groove length per revolution is:

$$GL = \pi * BOD * N / \cos \theta$$

where BOD is the core barrel outside diameter,
N is the number of auger flights, and
θ is the pitch angle of the auger flights.

If we use an EWM core barrel, the outside diameter is 1.4375 inches.

Assume an auger angle of 15°, and two auger flights.

The groove length, then, GL = 9.35 inch/revolution.

The minimum drill string rpm for the lunar core drill is 270 rpm.

$$\underline{VR = 23.73\ in^3/min}$$

The volume flow rate safety factor is:

$$\underline{n = VR / VP = 4.74.}$$

Since the safety factor is satisfactory, the previous specifications,

Groove Width = 0.1875

Groove Depth = 0.05

Auger Angle = 15°,

should be satisfactory.

APPENDIX D

Chip Basket Volume Calculations:

The volume of cuttings produced for each drill stroke is:

$$VP = A * L$$

where VP is the volume of cuttings produced for each stroke,
A is the cutting area of the drill bit, and
L is the length of the drill stroke.

The cutting area of the bit is:

$$A = \pi * (H^2 - C^2) / 4$$

where H is the hole diameter, and
C is the core diameter.

For "E" size drill equipment, H = 1.5 inches, and
C = 0.8125 inches.

Therefore, $A = 1.25\ in^2$.

If we use a 5 foot drill stroke,

$$\underline{VP = 75\ in^3.}$$

The volume of the inner tube is:

$$VI = LT * AT$$

where VI is the volume of the inner tube,
LT is the length of the inner tube, and
AT is the area of the inner tube.

The cross sectional horizontal area of the inner tube is:

$$AT = \pi * BID^2 / 4$$

where BID is the inner barrel inside diameter.

For "E" size drill equipment, the inside diameter of the inner barrel is 0.9385 inch.

Therefore, $AT = 0.69\ in^2$.

For our design, the length of the inner tube is 5 feet.

This results in

$$\underline{VI = 41.42\ in^3.}$$

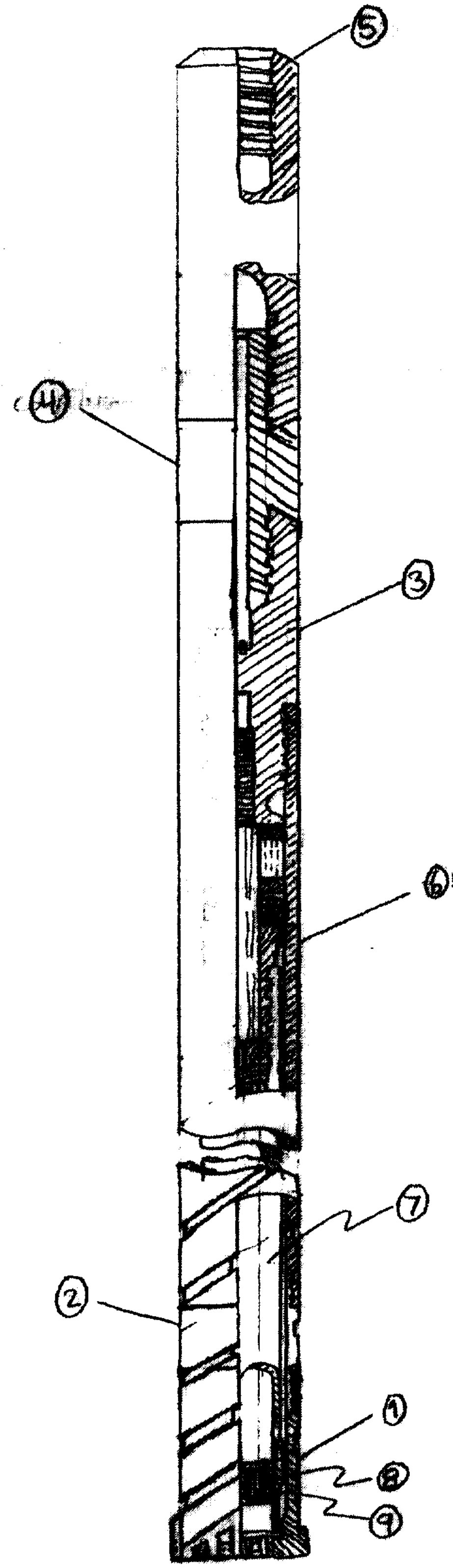
We must use 2 inner barrels to contain the cuttings, so that

$$\underline{VI = 82.84\ in^3.}$$

This leads to a safety factor of

$$\underline{n = VI / VP = 1.1.}$$

This is close to being unacceptable. This system can be tested and, if necessary, the drill stroke can be shortened or the chip basket section can be lengthened.

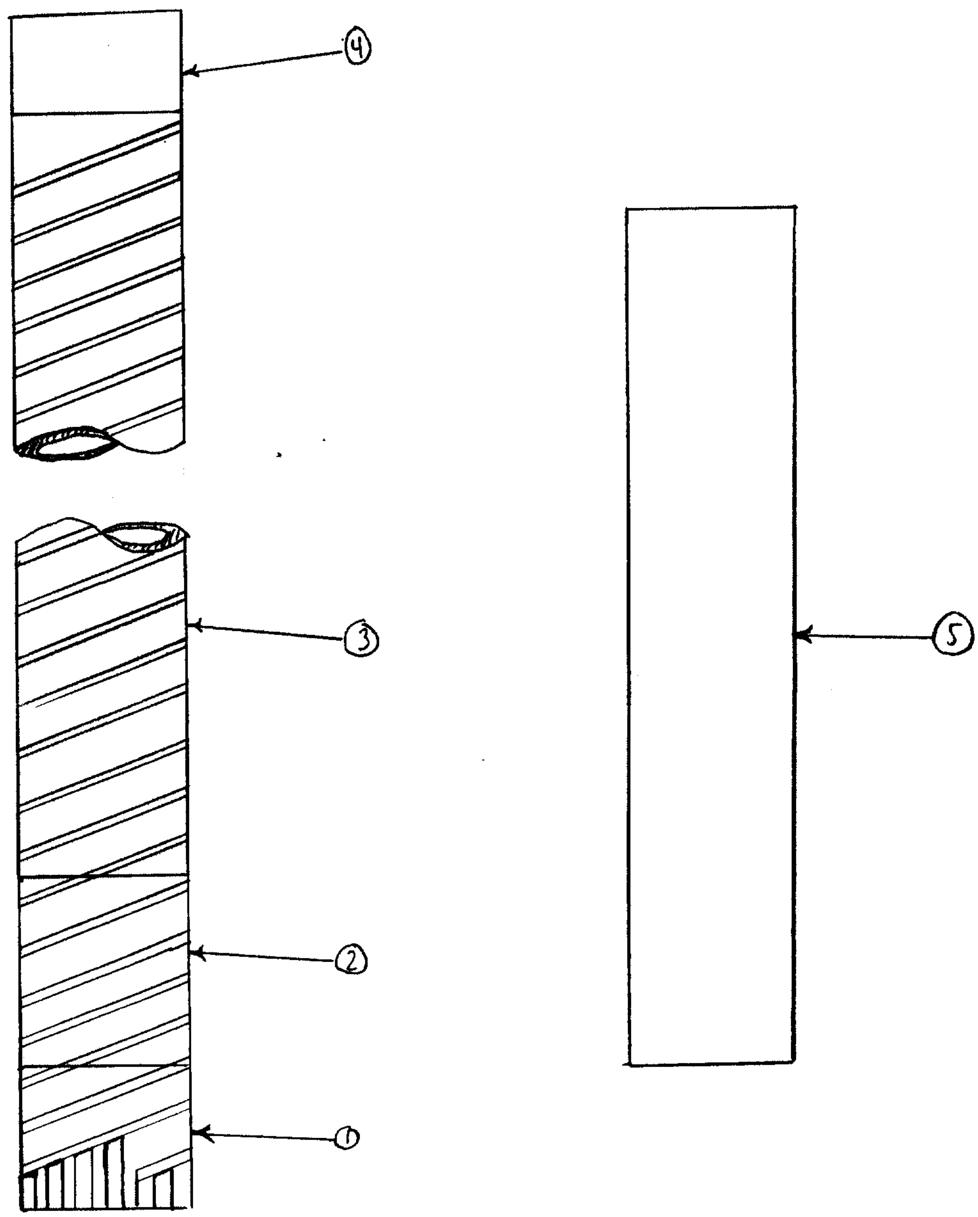


1. LUNAR CORE DRILL STRING
½ SCALE WIDTH WISE (LENGTH INDETERMINANT)

1. ACKER STANDARD DIAMOND CORING BIT SIZE EWG
2. ACKER TUNGSTEN CARBIDE REAMING SHELL
3. LONGYEAR HEAD ASSEMBLY, COMPLETE, EWM PART No. 16455
4. ACKER SIZE EW COUPLING

5. ACKER SIZE EW ROD
6. ACKER EWG OUTER TUBE
7. ACKER EWG INNER TUBE
8. + 9. CORE LIFTER & LIFTER CASE

OUTER TUBE INNER TUBE

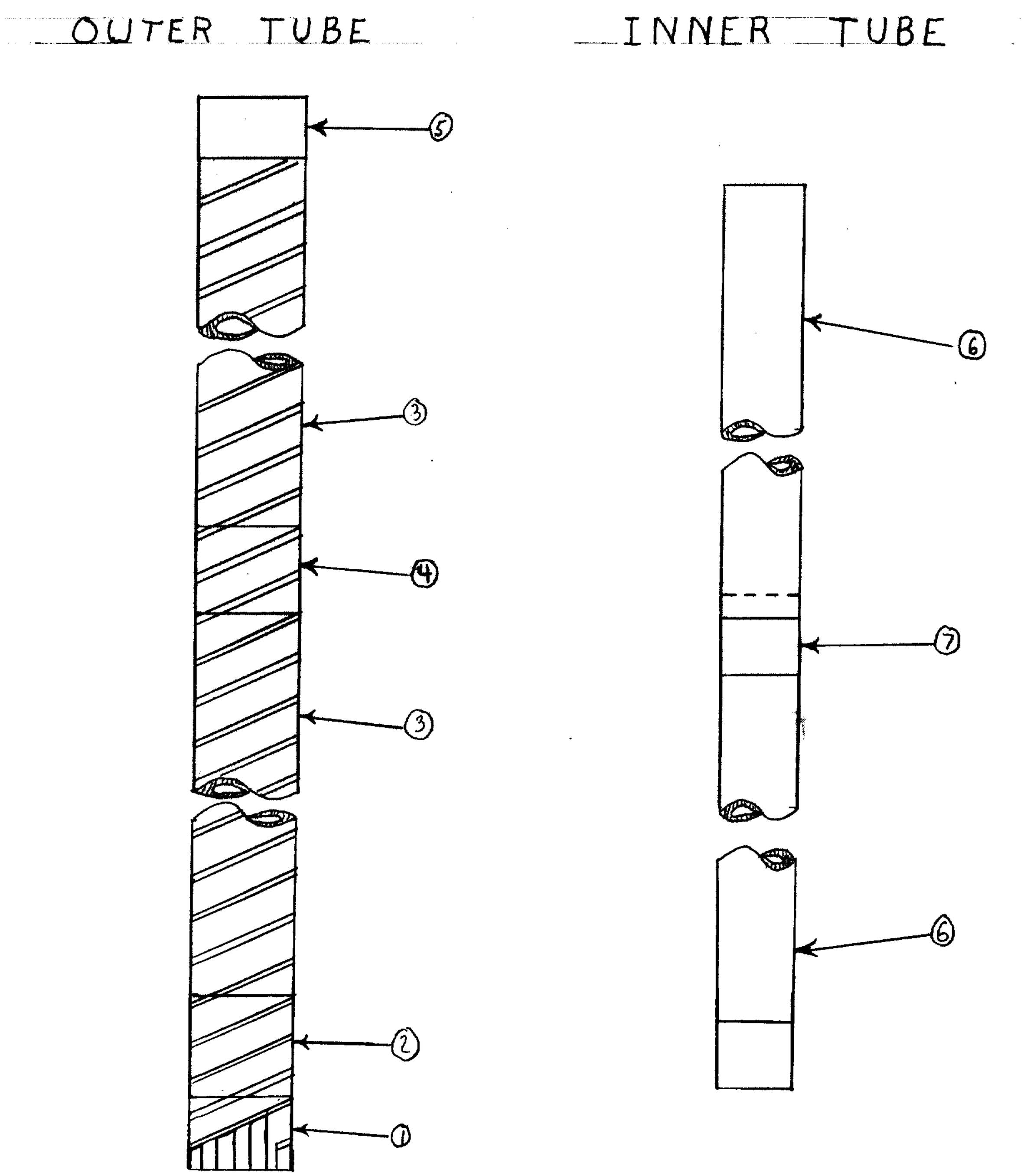


TITLE: DRILL
STRING ASSEMBLY
(0- 5 ft.)

1 DRILL BIT
2 EWG REAMING SHELL
3 EWM OUTER CORE BARREL
4 HEAD ASSEMBLY
5 EWM INNER CORE BARREL

DRAWING 1A

SCALE —



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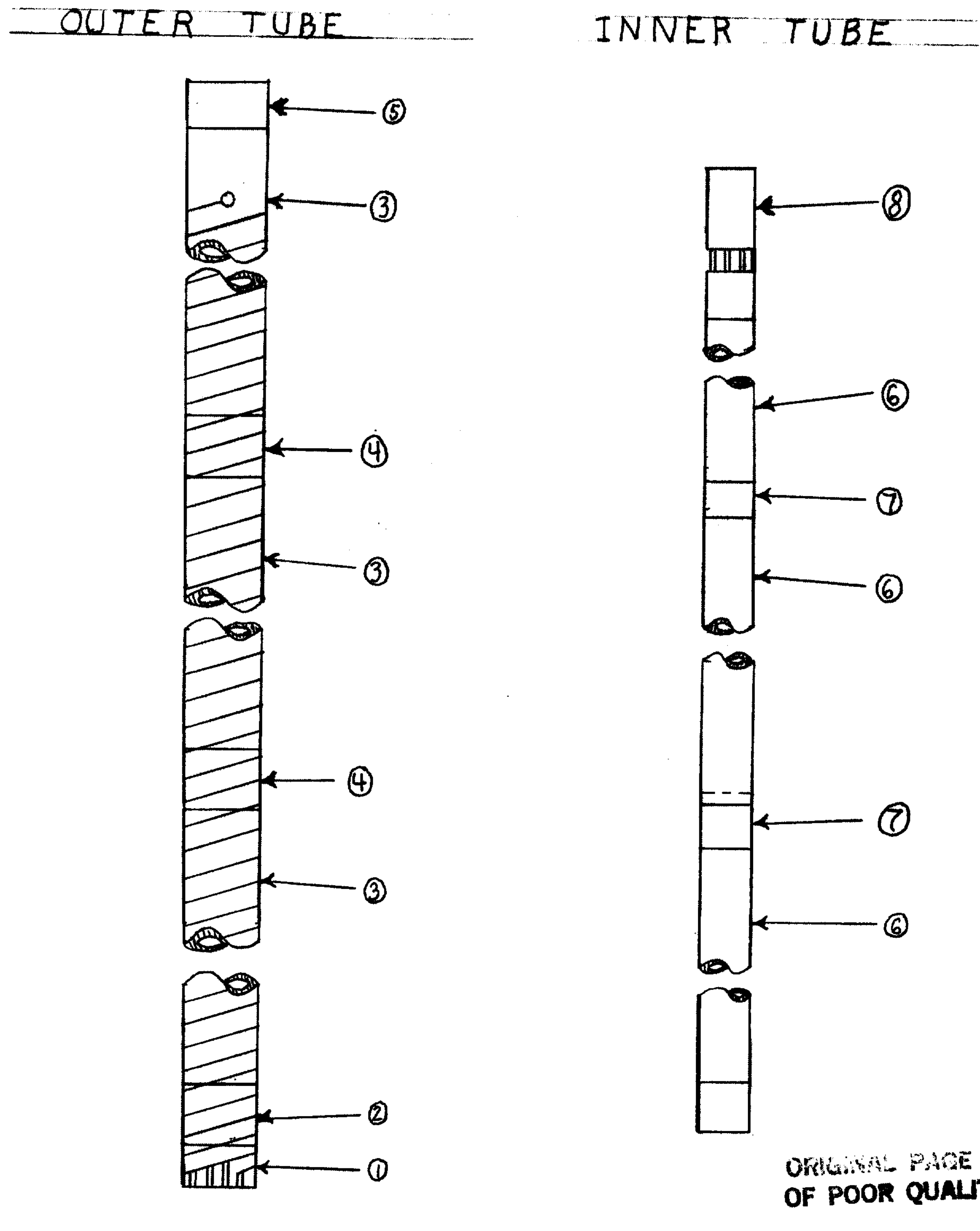
TITLE: DRILL STRING ASSEMBLY (5-10 ft)	① DRILL BIT ② EWG REAMING SHELL ③ EWM OUTER CORE BARREL ④ EWM REAMING SHELL BLANK ⑤ HEAD ASSEMBLY	⑥ EWM INNER CORE BARREL ⑦ INNER BARREL COUPLING DRAWING 1B SCALE —



TITLE: DRILL STRING ASSEMBLY
(10 ft. and below)

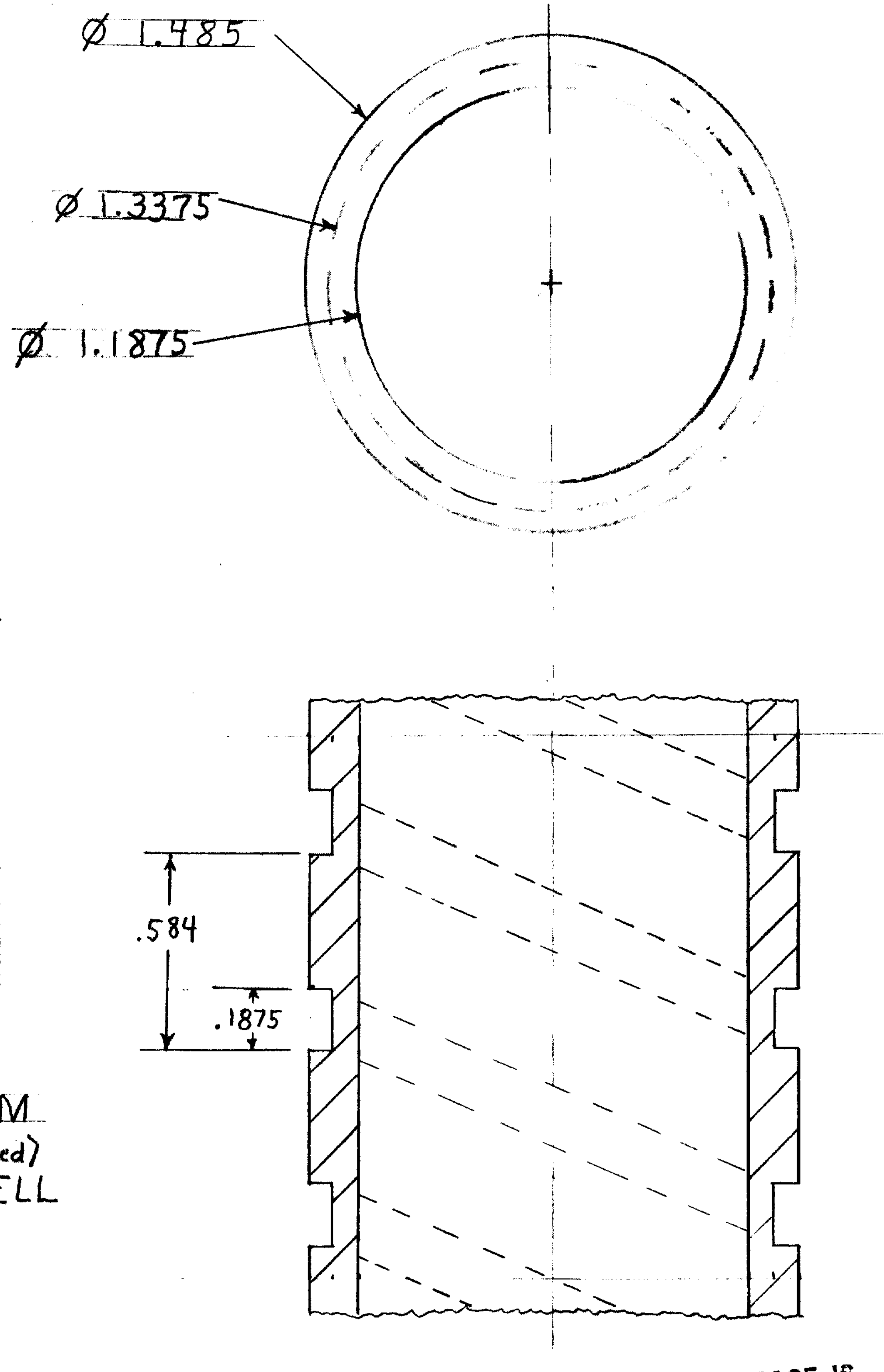
(PARTS LIST NEXT PAGE)

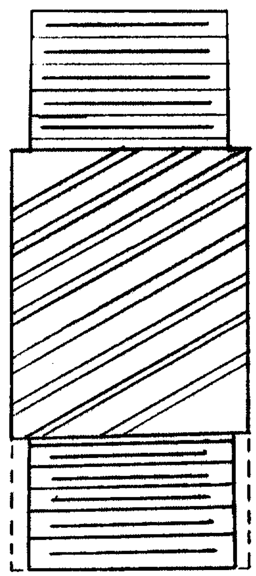
DRAWING 1C

SCALE —

PARTS LIST

PART	QTY	DESCRIPTION
1		Drill Bit
2	1	EWG Reaming Shell (Acker 301680)
3	1	EWM Core Barrel Assembly (Acker 20319-68)
	2	EWM Outer Core Barrel (Acker 100101)
4	2	Reaming Shell Blank (Acker 100110)
5		Head Assembly
6	2	EWM Inner Core Barrel (Acker 300106)
7	2	Inner Barrel Coupling (modified)
8	1	Chip Basket Entry Section (modified)
not shown	7	Drill Rod and Coupling (Acker 21004-5)
not shown	1	Motor to Drill String Coupling (modified)
not shown	1	Flat Plate Separator (modified)





MODIFIED EWM
AND EWG (dotted)
REAMING SHELL

TITLE: AUGER FLIGHT DIMENSIONS ON REAMING SHELL (EWM AND EWG (dotted))	EWG REAMING SHELL (ACKER 301680) AND REAMING SHELL BLANK (ACKER 100110) GROUND TO SPECIFICATIONS
	DRAWING 12+14
	SCALE DOUBLE

PARTS LIST

QTY	DESCRIPTION
1	EWG Reaming Shell (Acker 301680)
2	EWM reaming Shell Blank (Acker 100110)

Specifications

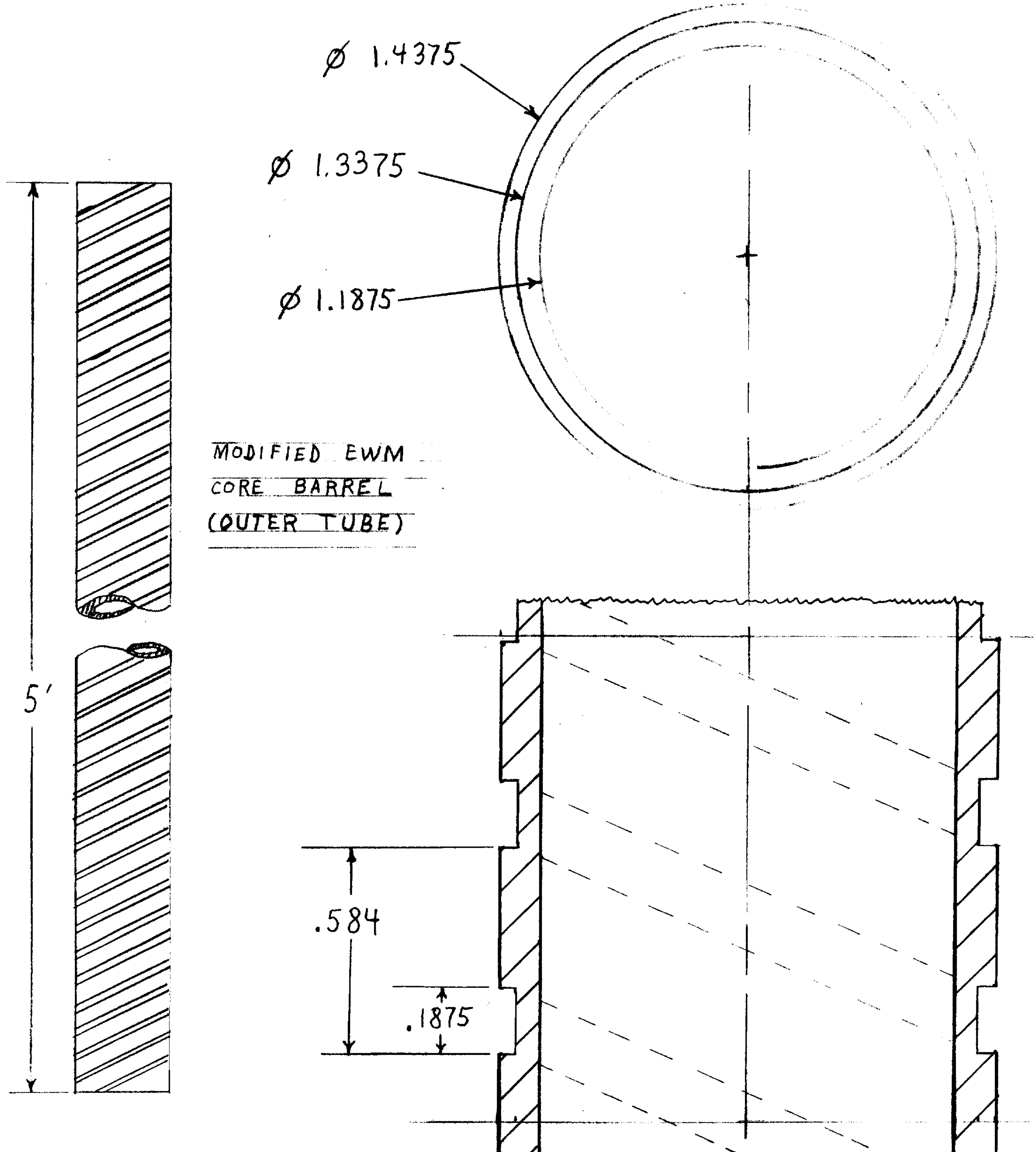
Groove Depth = 0.0738 inch

Groove Width = 0.1875 inch

Pitch Angle = 15

Instructions

Grind drill string assembled and mark coupling order of drill string components to ease later assembly.



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TITLE: AUGER FLIGHT DIMENSIONS ON OUTER CORE BARREL (EWM)	EWM OUTER CORE BARREL (5 ft.) (ACKER 100101) GROUND TO SPECIFICATIONS

DRAWING 13

SCALE 2.5" = 1"

PARTS LIST

QTY	DESCRIPTION
2	EWM Outer Core Barrel (Acker 100101)
1	EWM Outer Core Barrel Assembly (Acker 20319-68)

Specifications

Groove Depth = 0.05 inch

Groove Width = 0.1875 inch

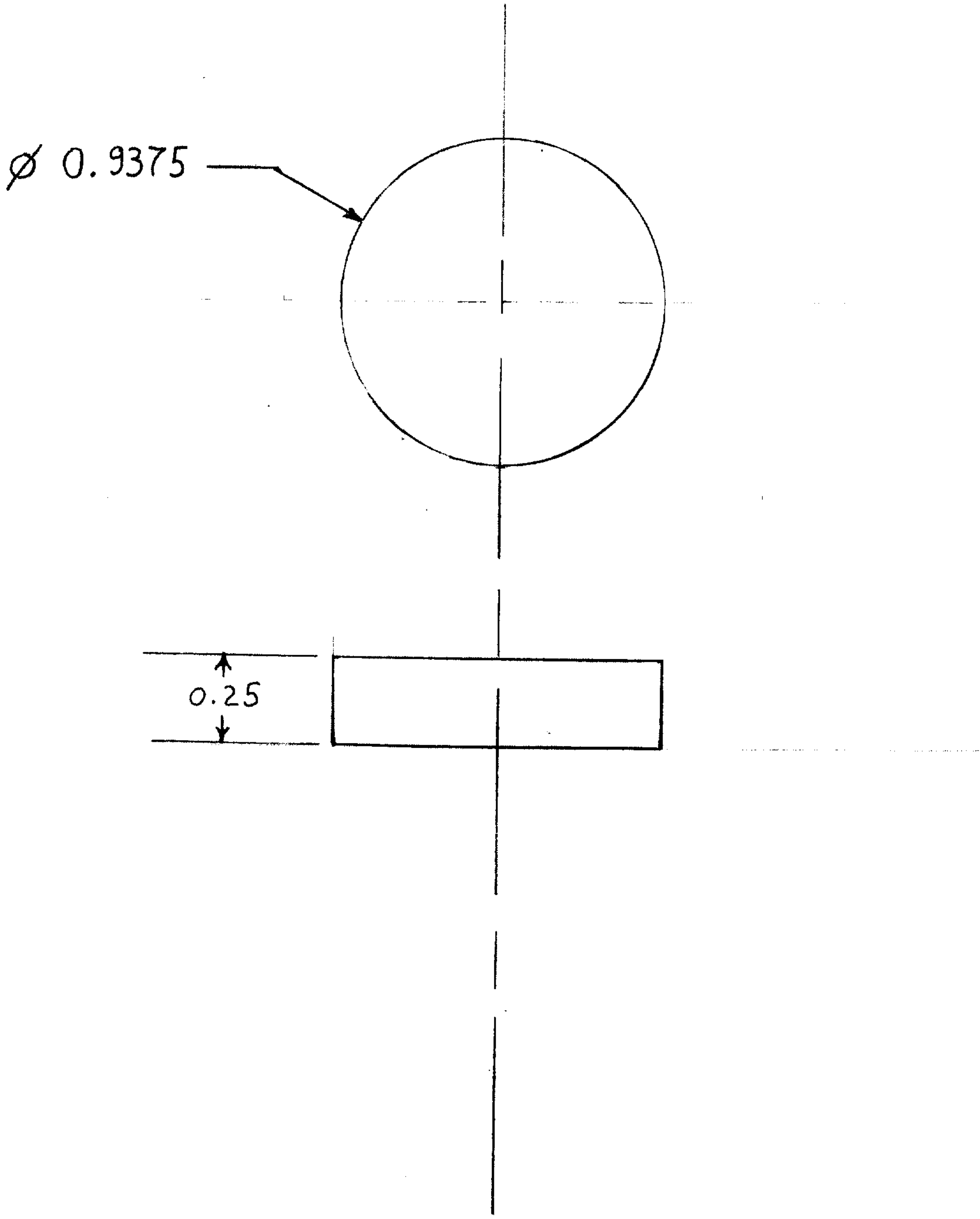
Pitch Angle = 15

2 Auger Flights

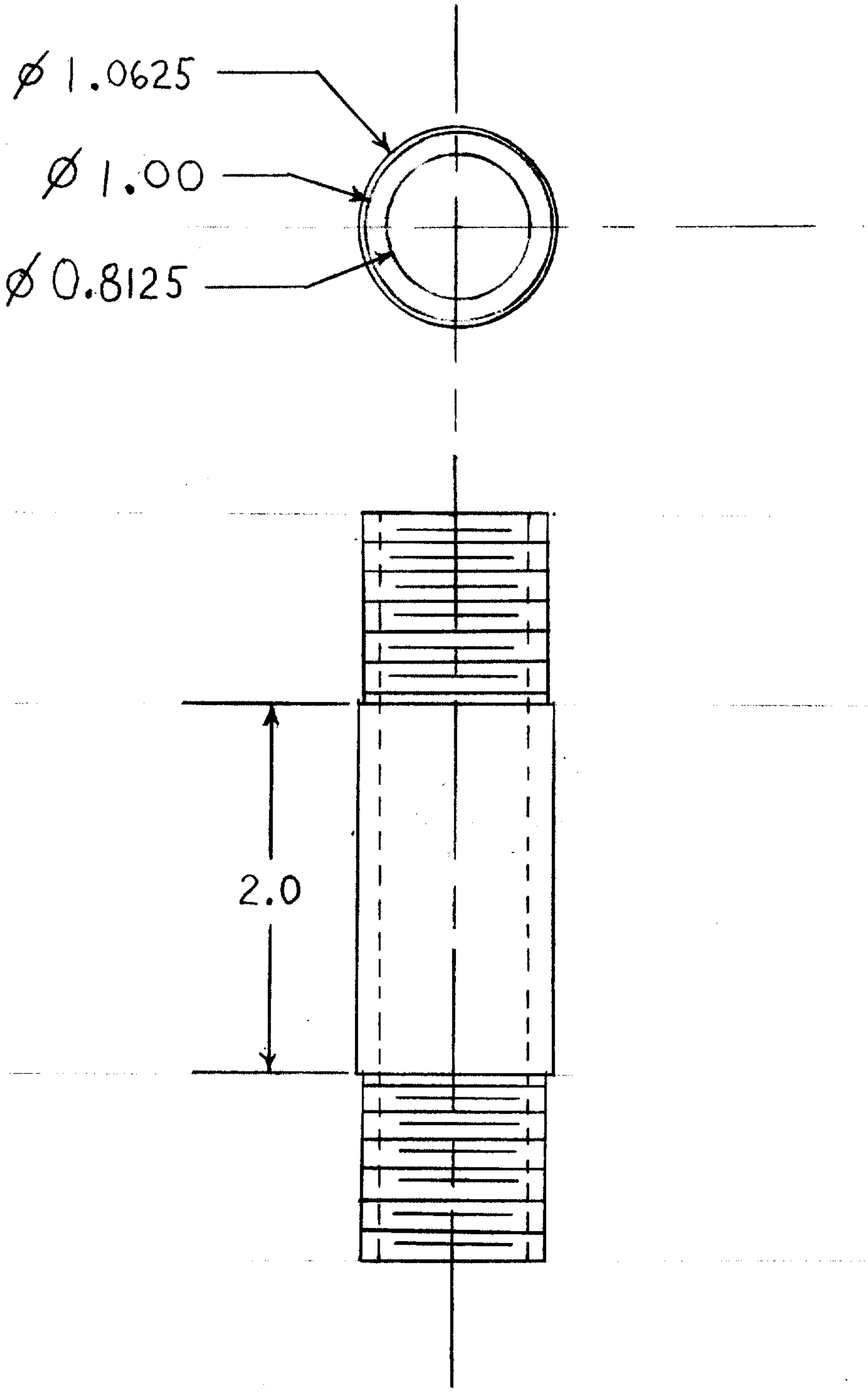
Instructions

Grind Drill String assembled and mark coupling order of components to ease later assembly.

Flights end 5 inches from top of third barrel. Drill a 0.1875 inch hole at the end of each of the auger flights.



TITLE: INNER BARREL FLAT PLATE SEPARATOR	FLAT PLATE STEEL (UNS G10150 HR) FILLET WELD UNDERNEATH AT 0.5 inch ABOVE THREADS AT BOTTOM OF MIDDLE INNER CORE BARREL.
DRAWING	16A
SCALE	DOUBLE



TITLE: INNER BARREL COUPLING

DRAWING 17

SCALE FULL

PARTS LIST

QTY	DESCRIPTION
2	Steel Tube (UNS G10150 HR)

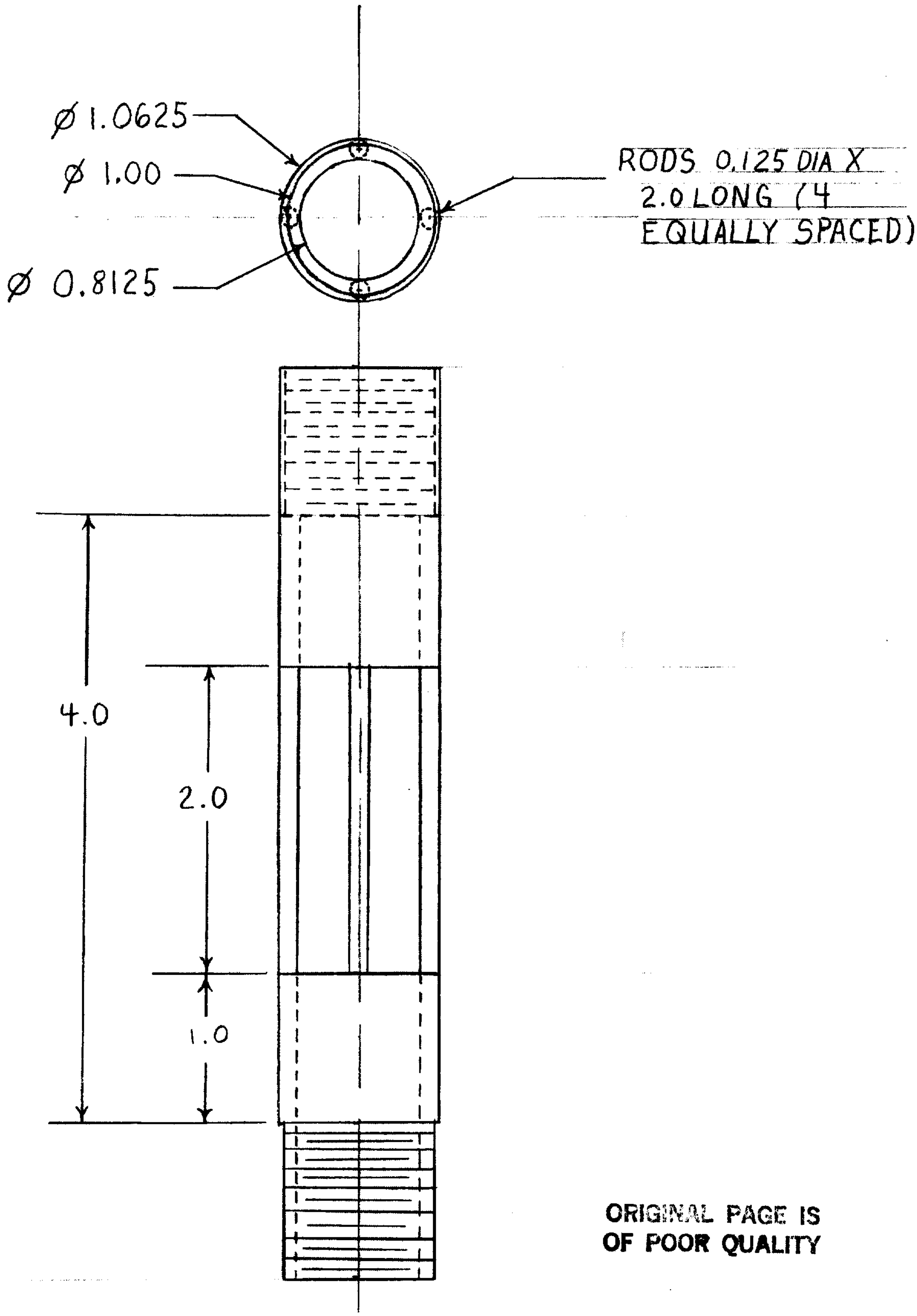
I.D. = 0.8125 inch

O.D. = 1.0625 inch

Length = 4 inches

Instructions

Thread tube at both ends to the same dimensions as the inner barrel threads.



ORIGINAL PAGE IS
OF POOR QUALITY

TITLE: INNER
BARREL CHIP BASKET
ENTRY SECTION

DRAWING 18

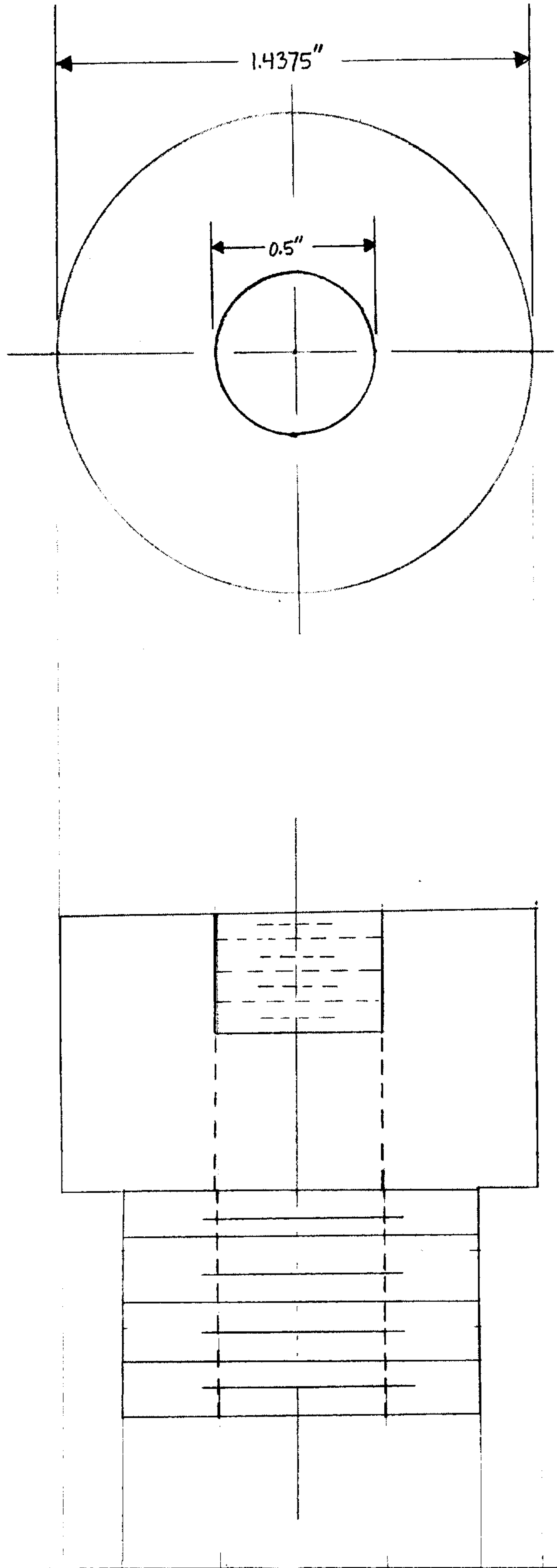
SCALE FULL

PARTS LIST

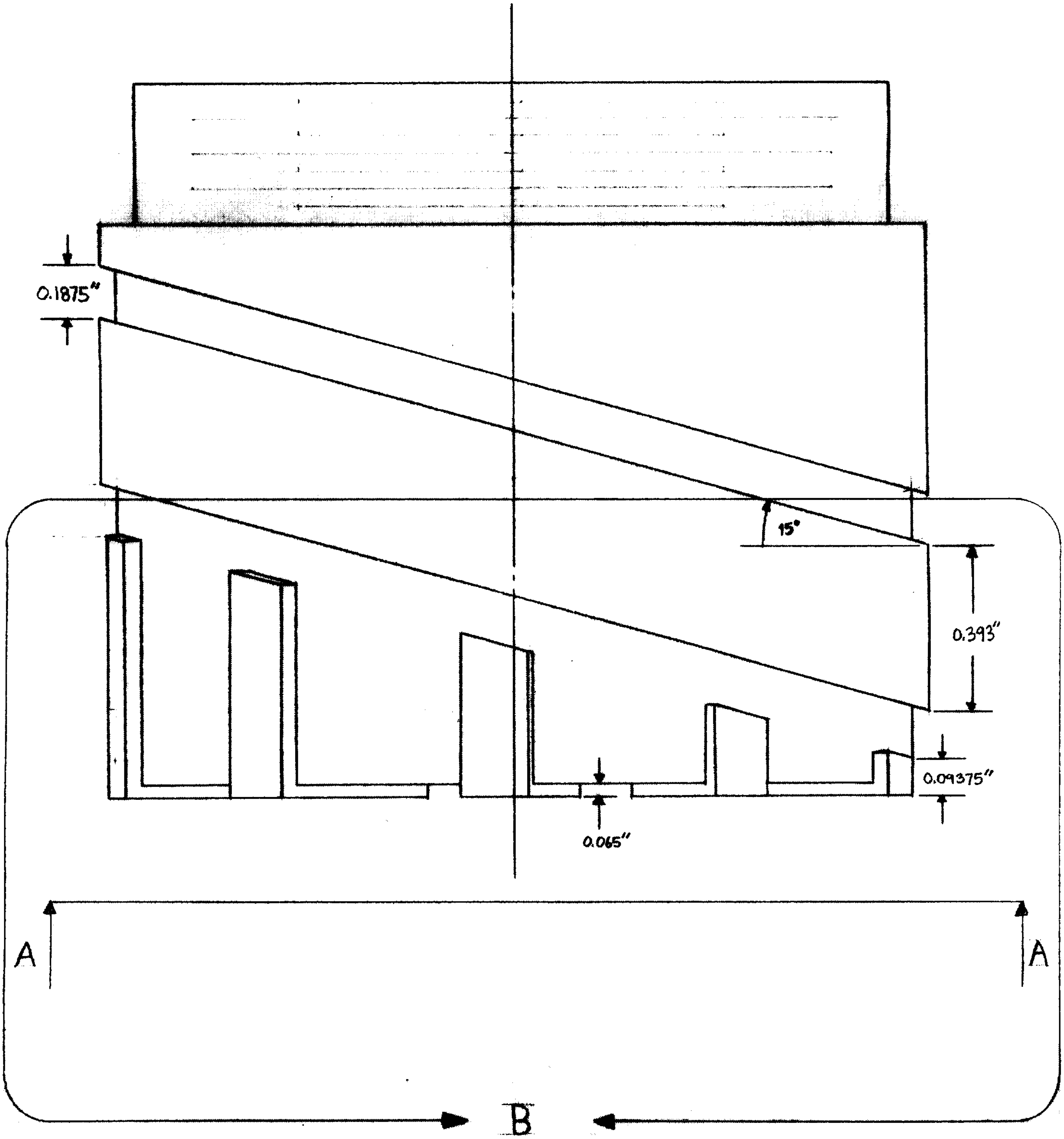
QTY	DESCRIPTION
4	0.125 inch X 2 inch long Steel Rod (UNS G10150 HR)
1	Tube Steel (UNS G10150 HR)
	ID = 0.8125 inch
	OD = 1.0625 inch
	Length = 4 inches

Instructions

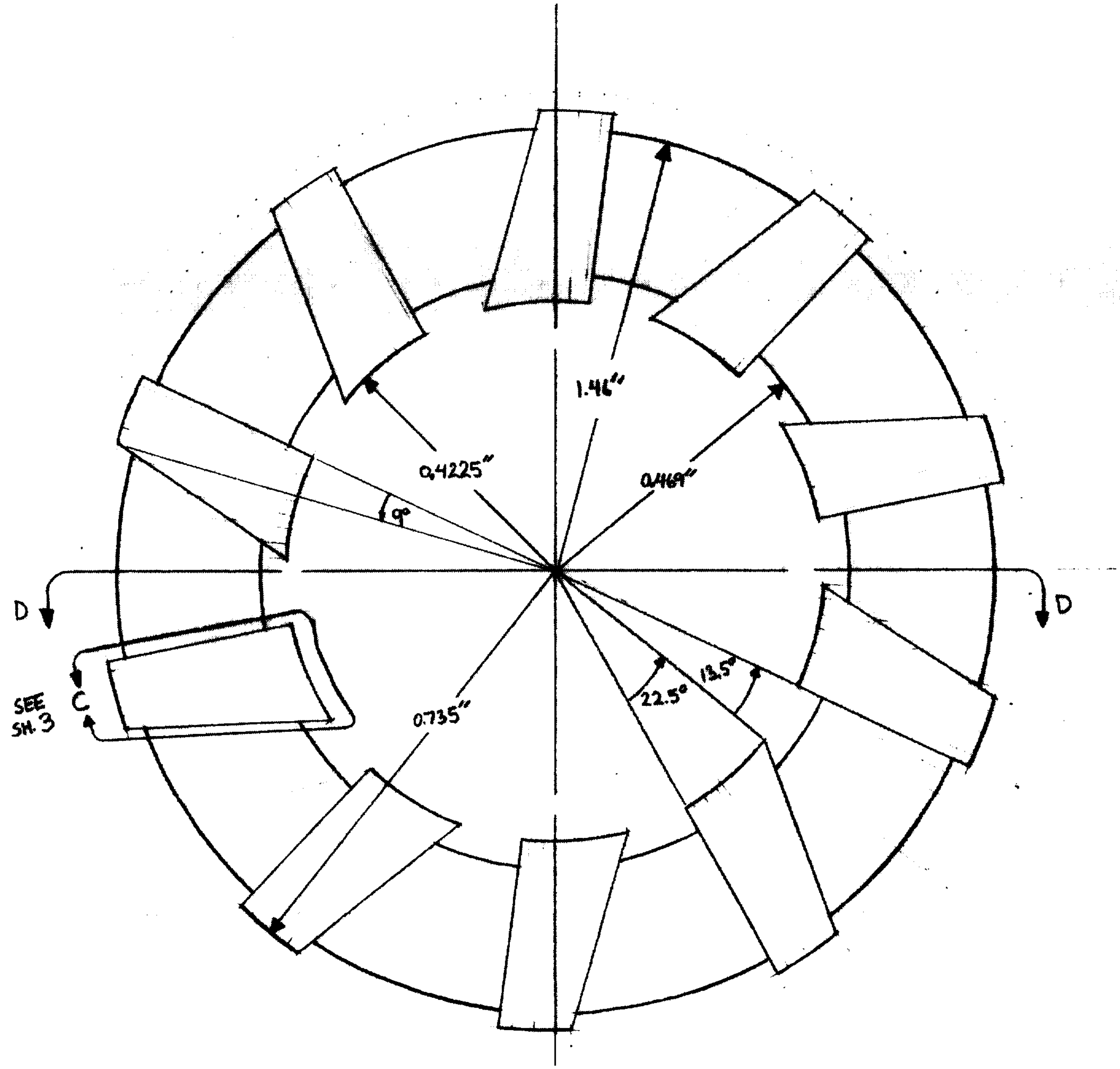
Cut steel tube in half. Weld steel rods 90 degrees apart to divided section of the steel tube. Top thread dimensions same as head assembly inner barrel dimensions, and bottom thread dimensions same as inner barrel thread dimensions.



MOTOR-DRILL STRING CONNECTION	SCALE 2:1
	OUTSIDE THREADS ARE SAME PITCH AND DIAMETER. AS THREADS ON ACKER HEAD ASSEMBLY AND DRILL RODS
	DRAWING 19

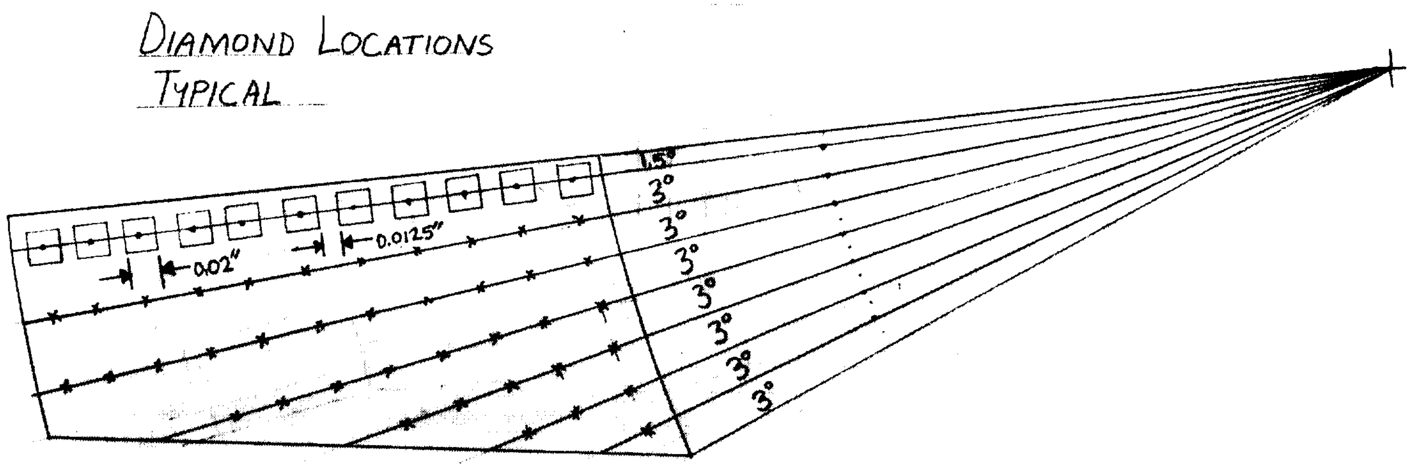


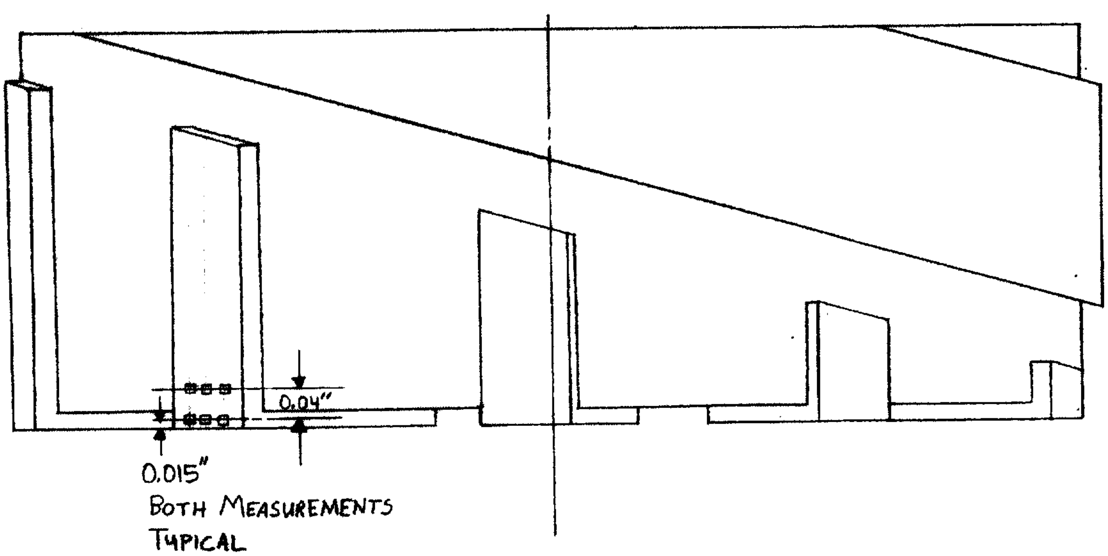
DIAMOND CORE BIT FRONT VIEW SCALE 4:1



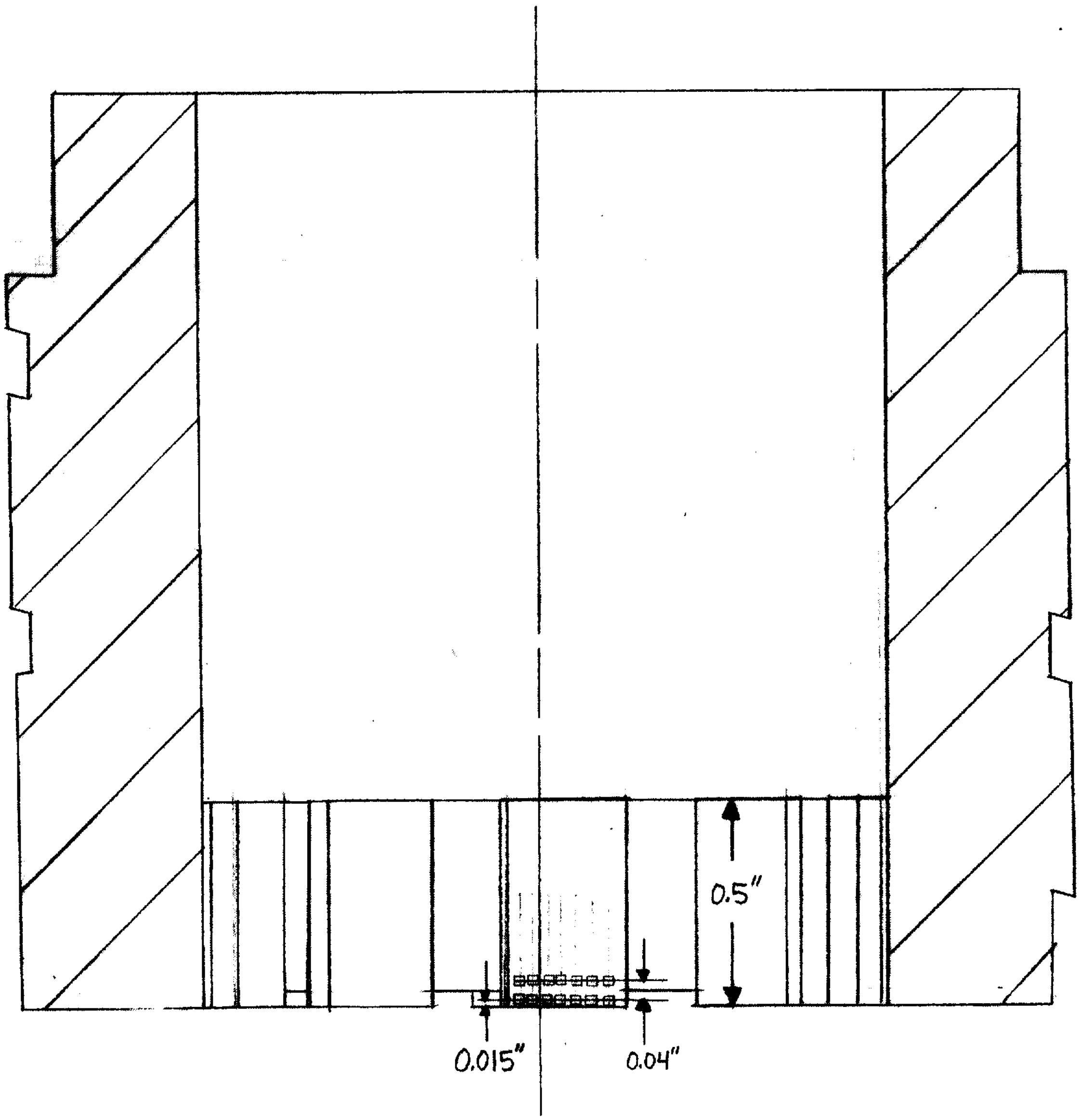
SECTION A-A

SCALE 4:1





VIEW C (TOP) SCALE 8:1
SECTION B-B (BOTTOM) SCALE 4:1



SECTION D-D

SCALE 4:1

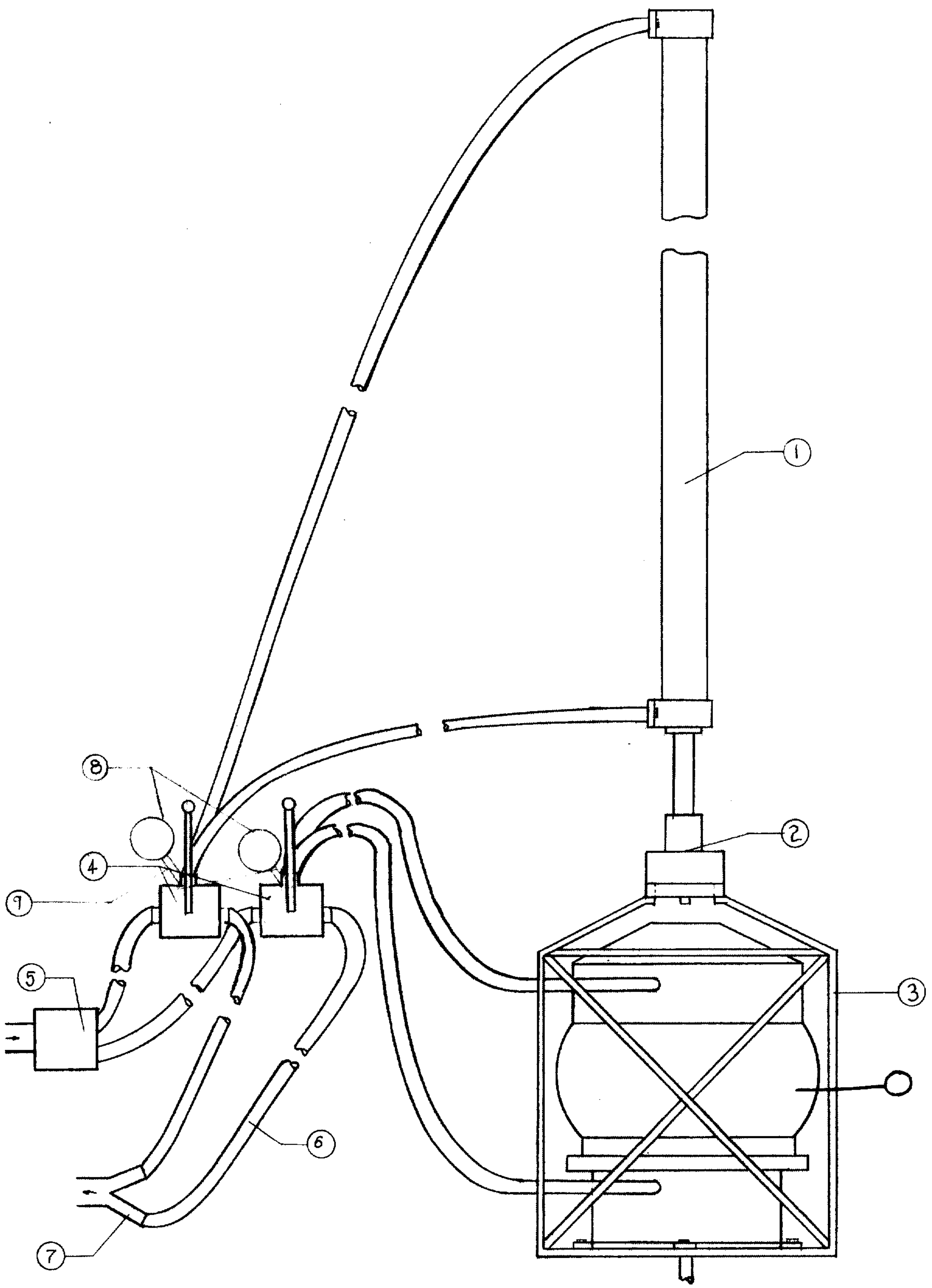
SHEET 11C

NOTES:

1. OCTAHEDRON CRYSTAL STRUCTURE
2. THREE PIECE MOLD TO BE CAST IN BY THE ACKER DRILL CO. INC.
3. ACKER DRILL CO. INC. TO USE MOLD TO ALLOW PIPS TO BE DRILLED TO A SPECIFIC DEPTH AT A GIVEN DIAMOND ORIENTATION ANGLE WITHIN ± 5 MINUTES OF ARC AND TO WITHIN ± 0.001 in. OF SPECIFIC LOCATIONS. EACH OF THREE PIECES MACHINED TO TOLERANCE OF ± 0.001 in.
4. POWDER METAL LOADING, COMPRESSION, BLANK ASSEMBLY, AND SINTERING.

LIST OF MATERIALS

QUANTITY	DESCRIPTION	MATERIALS	NOTES
530	DIAMONDS	AAAA QUALITY WEST AFRICAN BOARTZ 20/CARAT	1
1	CORE DRILL BIT MATRIX	TYPE 4 PROPRIETARY POWDERED METAL ALLOY FROM CHRISTENSEN DIAMOND PRODUCTS COMPANY	2, 3
—	DIAMOND CORE BIT	ASSEMBLY	4

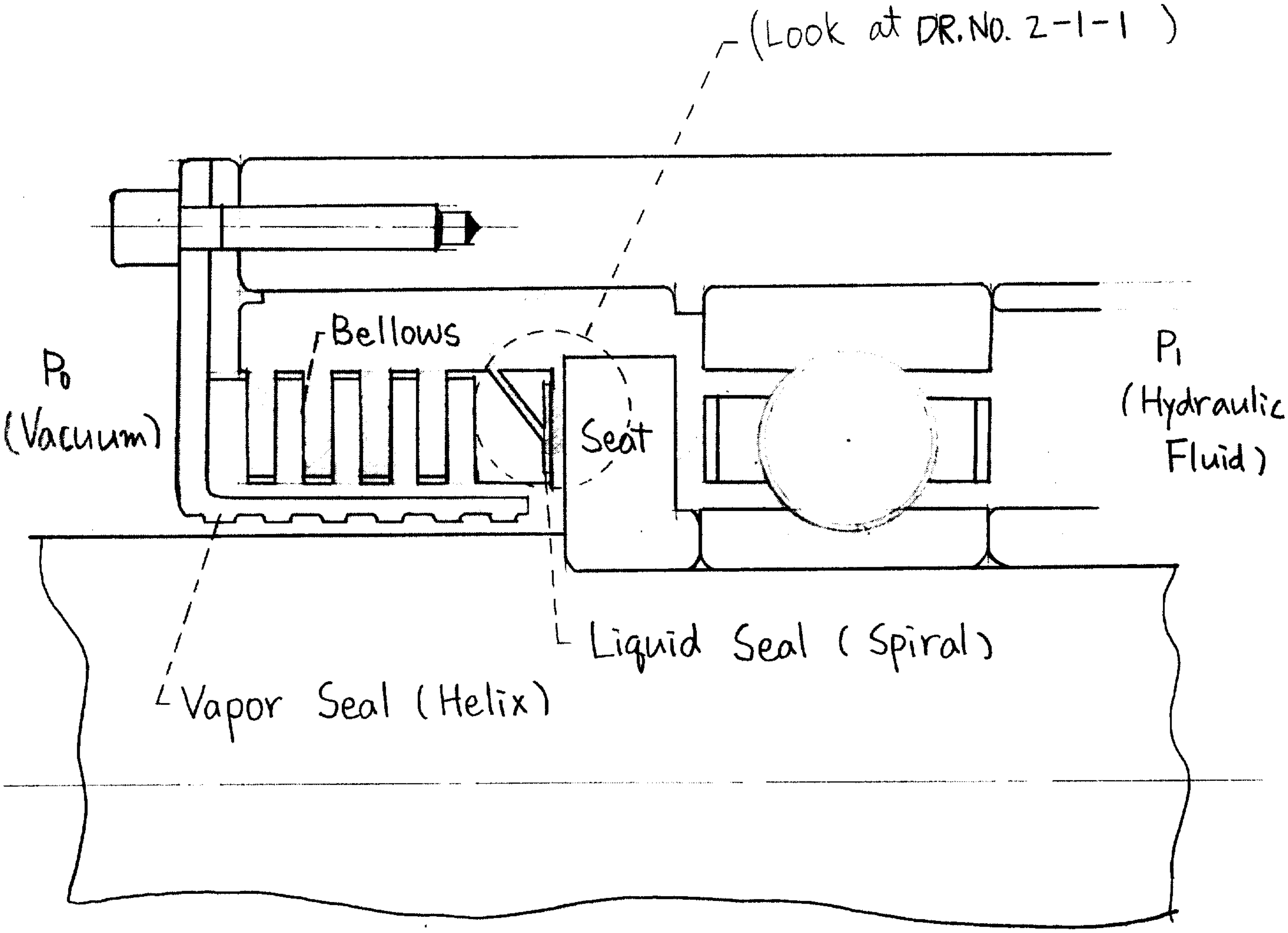


TITLE: Hydraulic Component Assembly

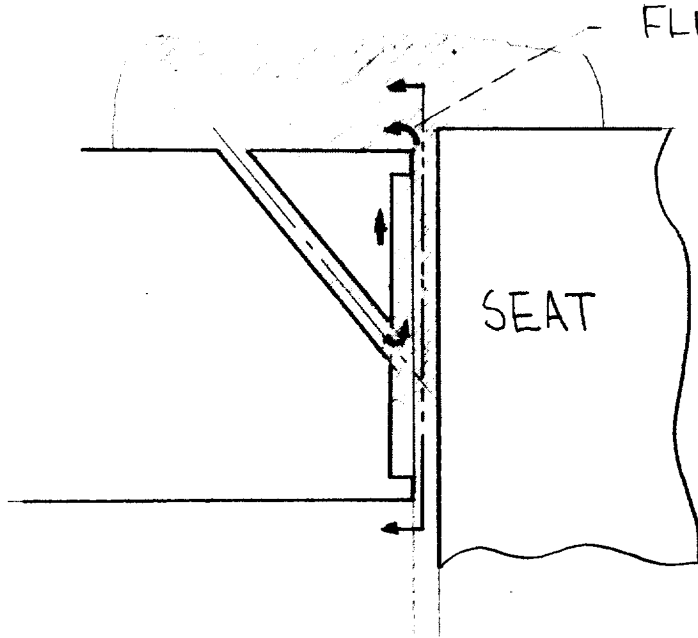
① (drawing # 2-3)
② (drawing # 2-4)
③ (drawing # 2-2)
④ Prince Hydraulics RD 2100 T3
⑤ Prince Hydraulics RD 200 (4:1)
⑥ AEROQUIP CORP. HOSE 680-8-L
⑦ (nao-Tite, Inc. FSS1FTO.5NST
⑧ Templeton, Kenly & Co. model # 18900
⑨ Templeton, Kenly & Co. model # 18976

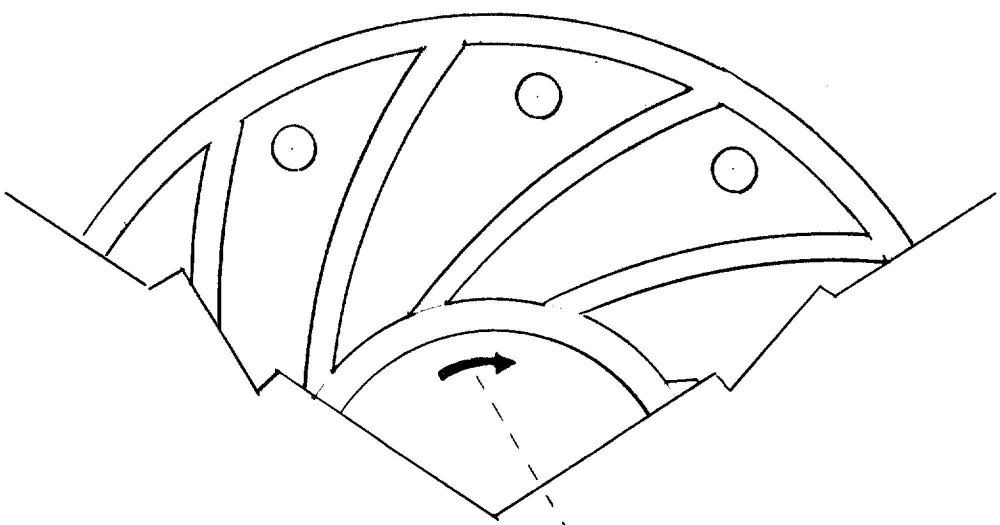
2

SCALE 1:6



DRAWING NO: 2-1	COMMENTS:
TITLE: ROTATE SHAFT SEAL TO VACUUM	

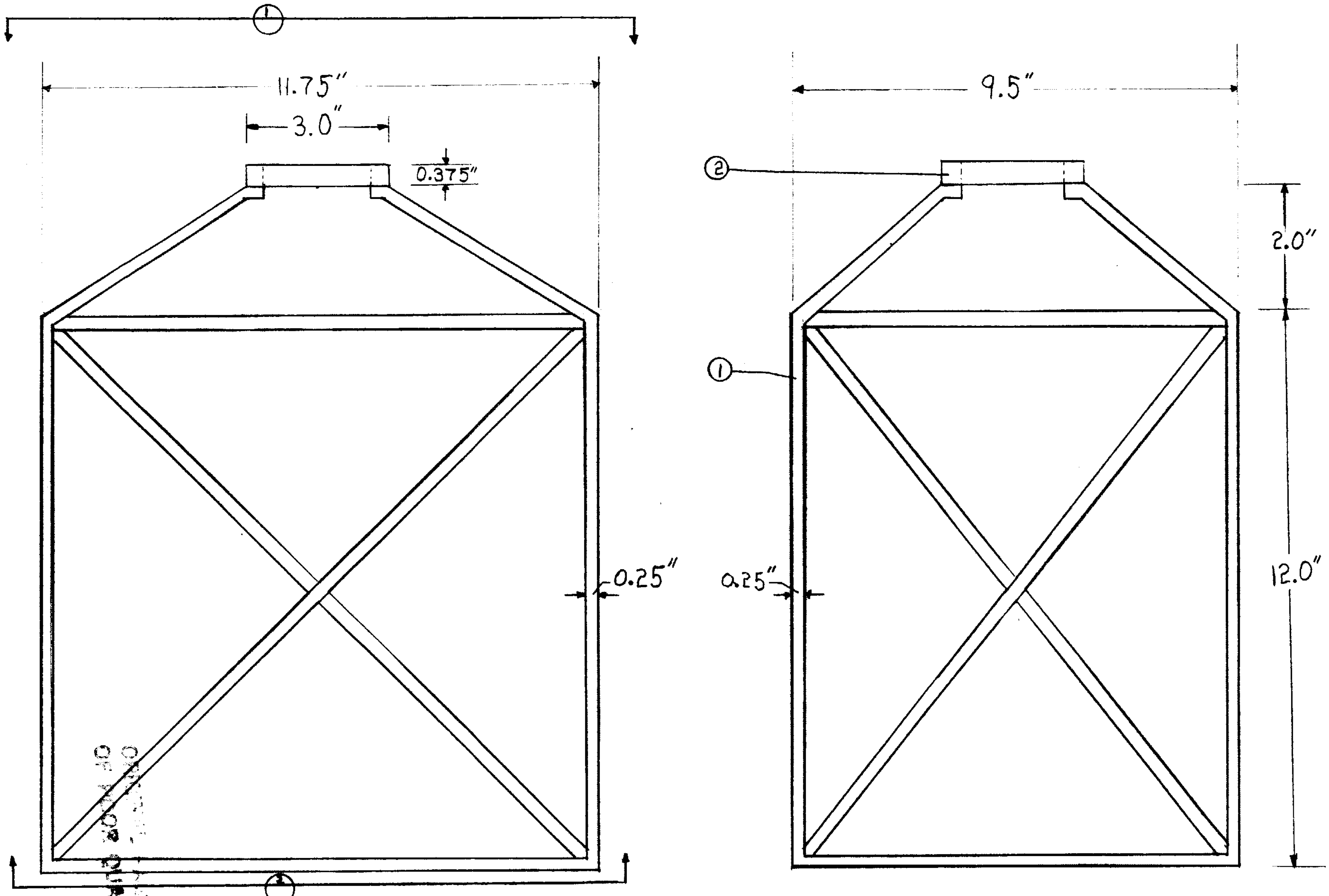




DRAWING NO.: 2-1-1

TITLE:
SPIRAL PUMPING

COMMENTS



TITLE: Motor Frame/ Mount

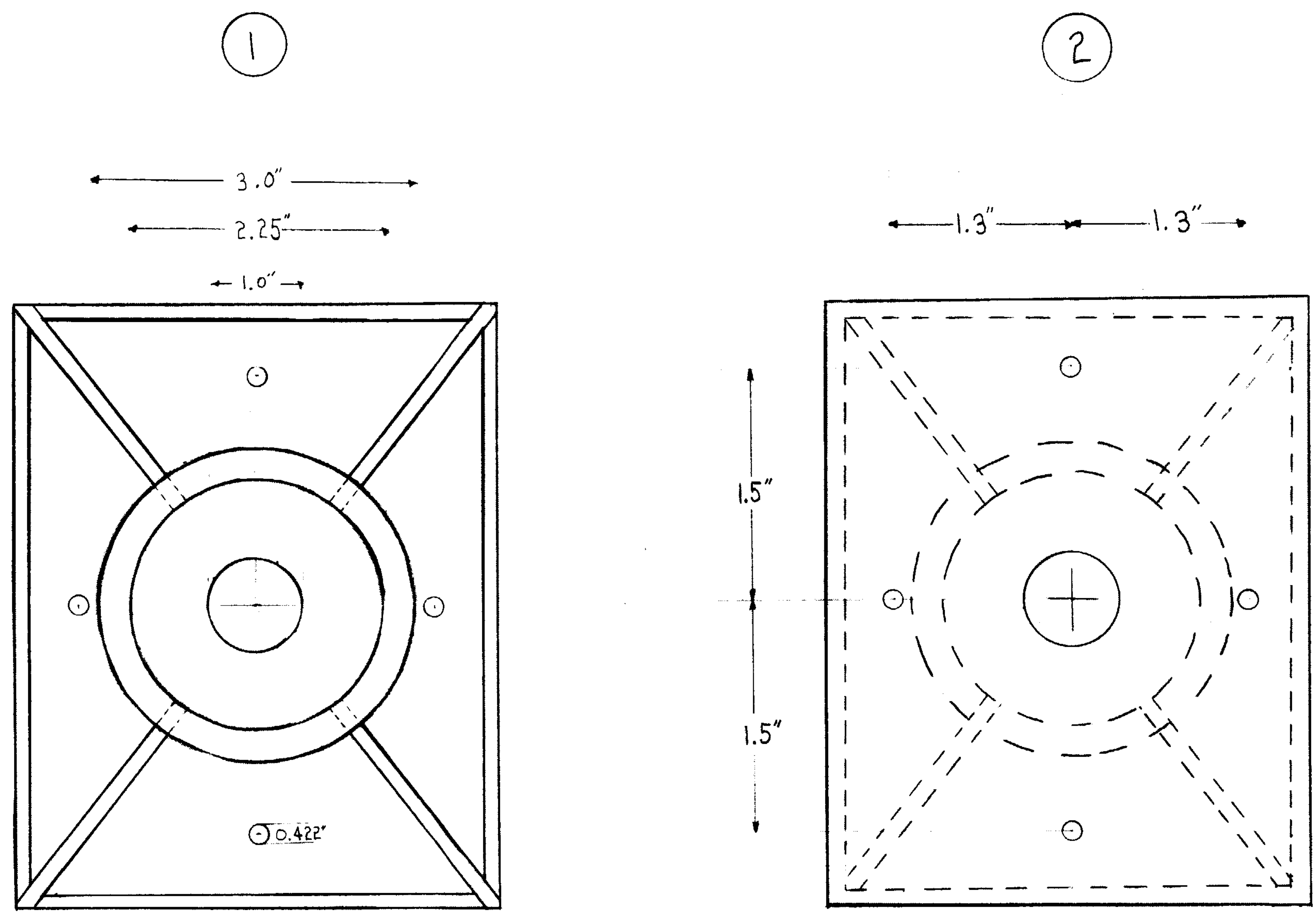
① rectangular frame struts ; 2330 steel drawn @ 400° F

② frame collar ; 1080 steel

Note: All frame connections are welded

2-2 A

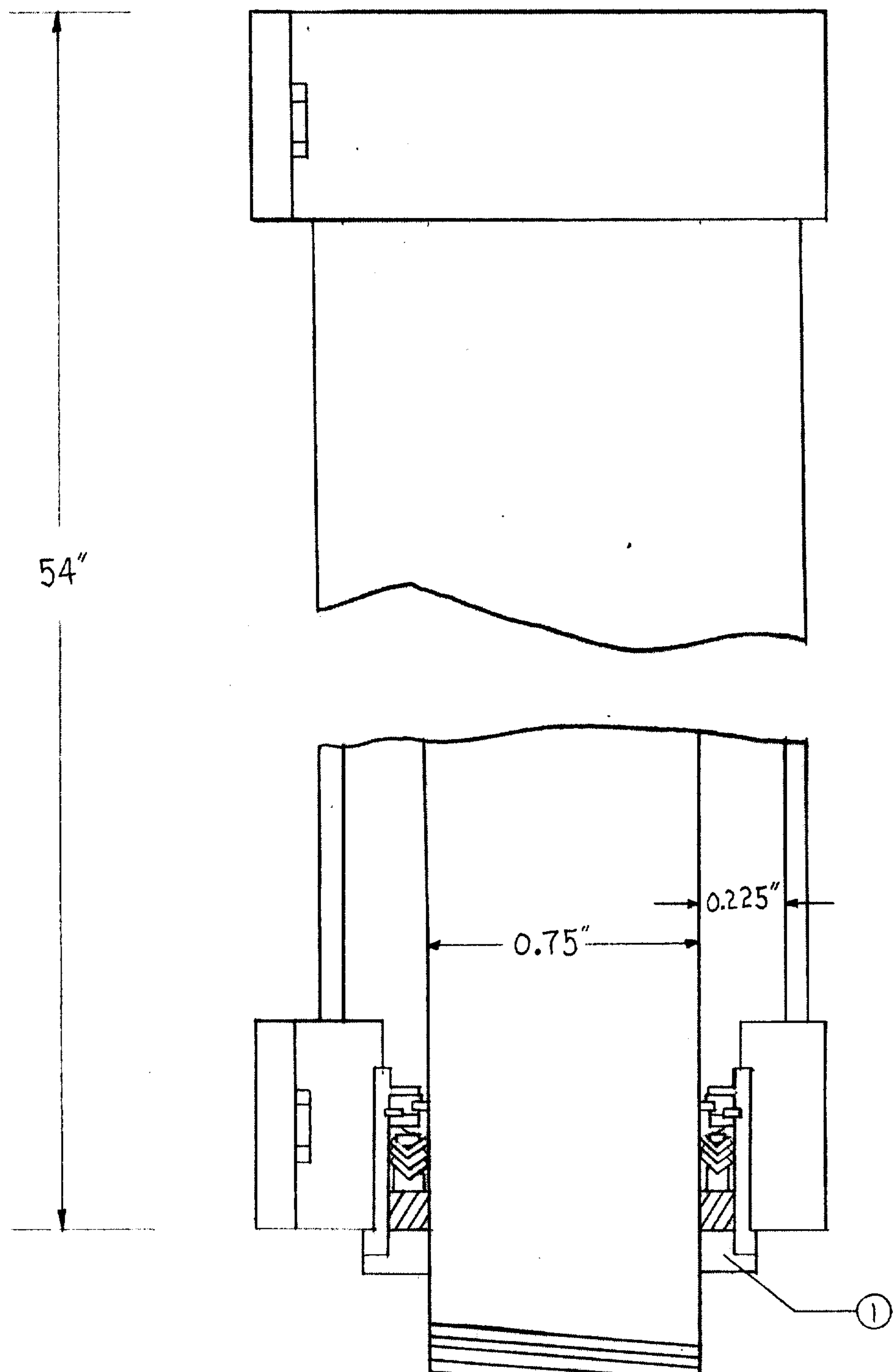
SCALE 1:3



TITLE: Motor Frame/Mount

2-2B

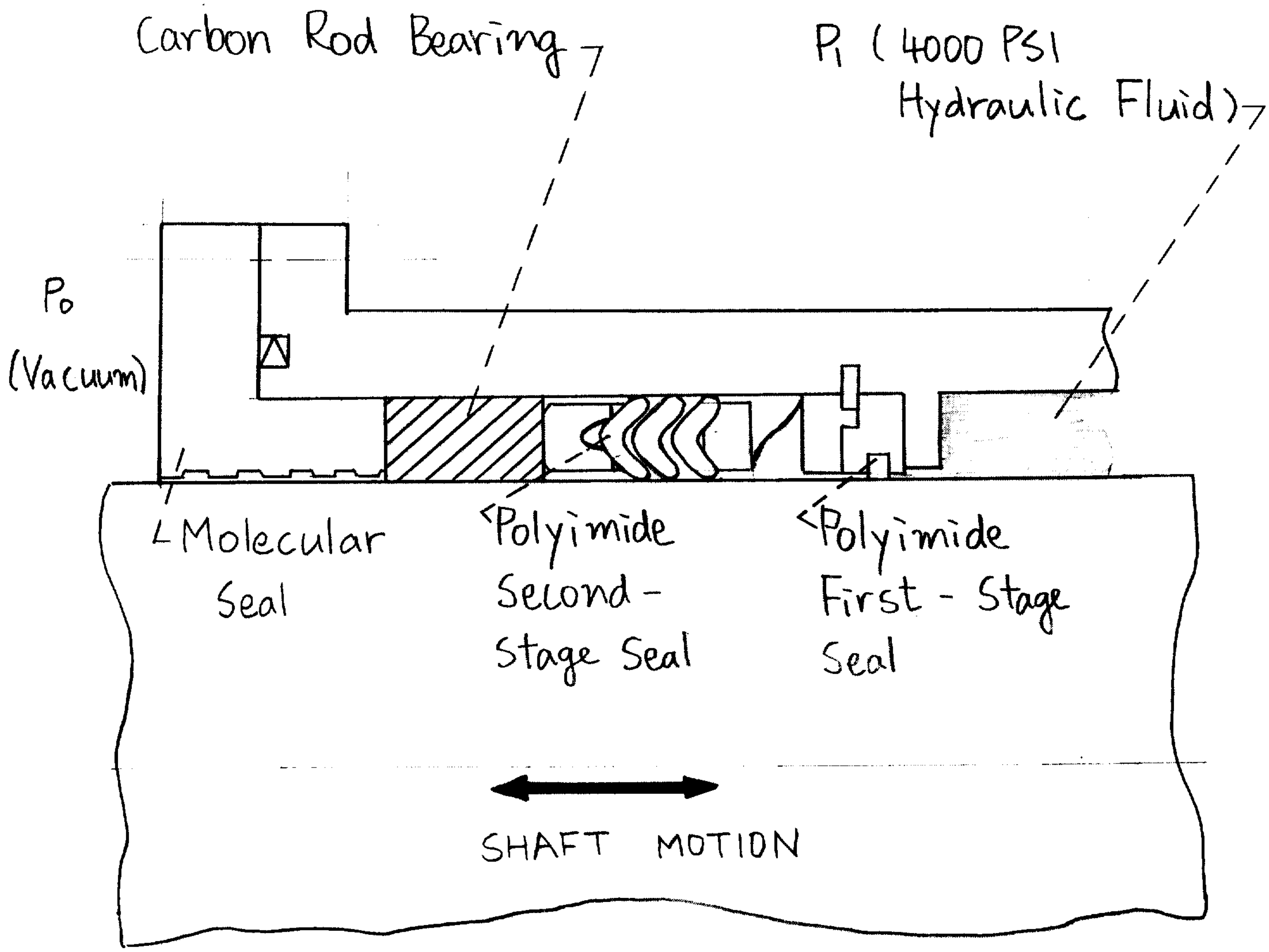
SCALE 1:3



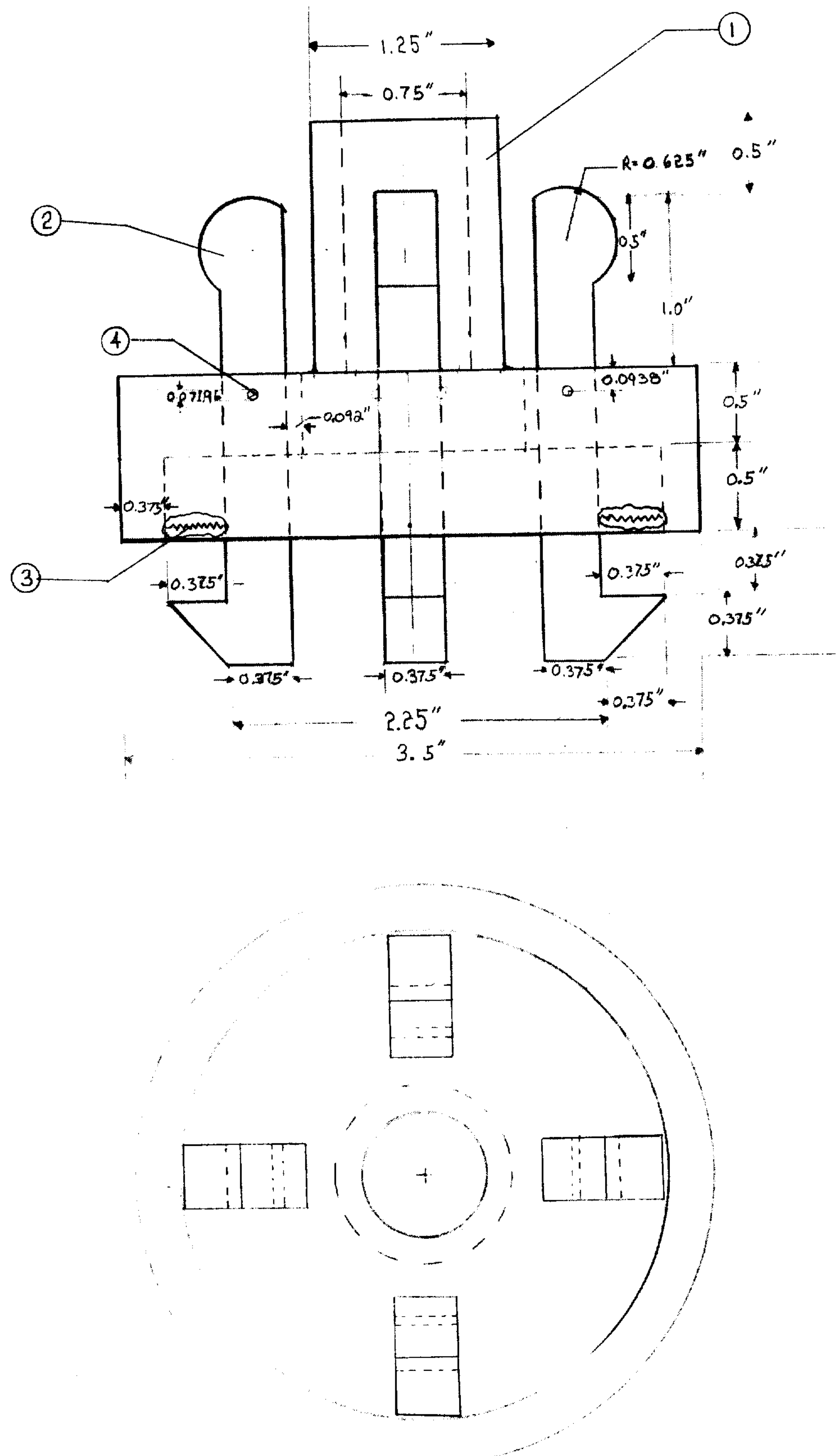
TITLE: Lynair Inc.
H-1.2-A-3-1-54-0.75-S
with modifications
shown

① (drawing # 2-1-1)

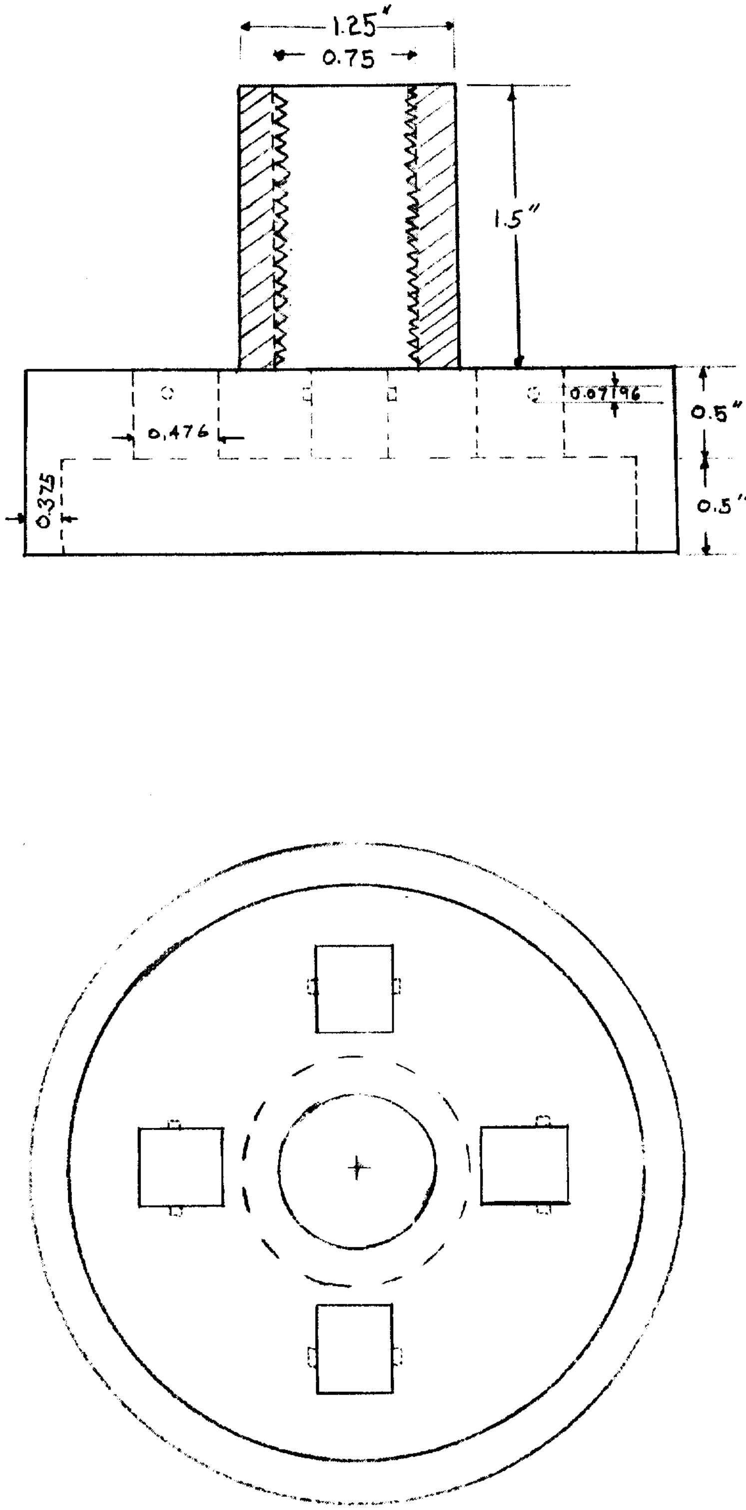
2-3
SCALE 2:1



DRAWING NO: 2-3-1	COMMENTS:
TITLE: ACTUATOR ROD SEAL	



TITLE: Cylinder Rod - Motor Frame/Mount Adapter	① (drawing #2-4-1) ② (drawing #2-4-2) ③ Retainer spring: 1065 steel, 20 coils, dia.=0.015 in, prestress=1.5 lb 26 gauge ④ Pivot Pin: 1080 Steel	# 2-4 SCALE 1:1



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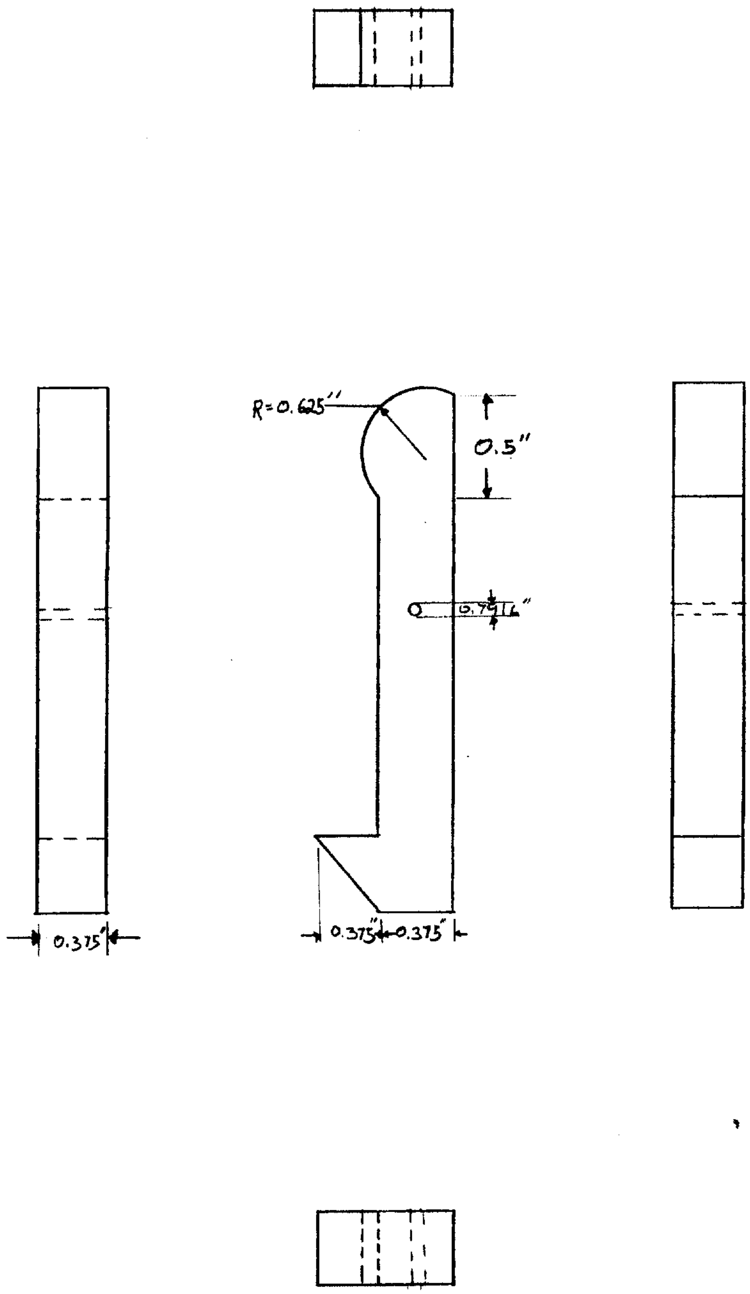
OF POOR QUALITY

TITLE: Adapter Housing

material: 2350 Steel

2-4-1

SCALE 1:1



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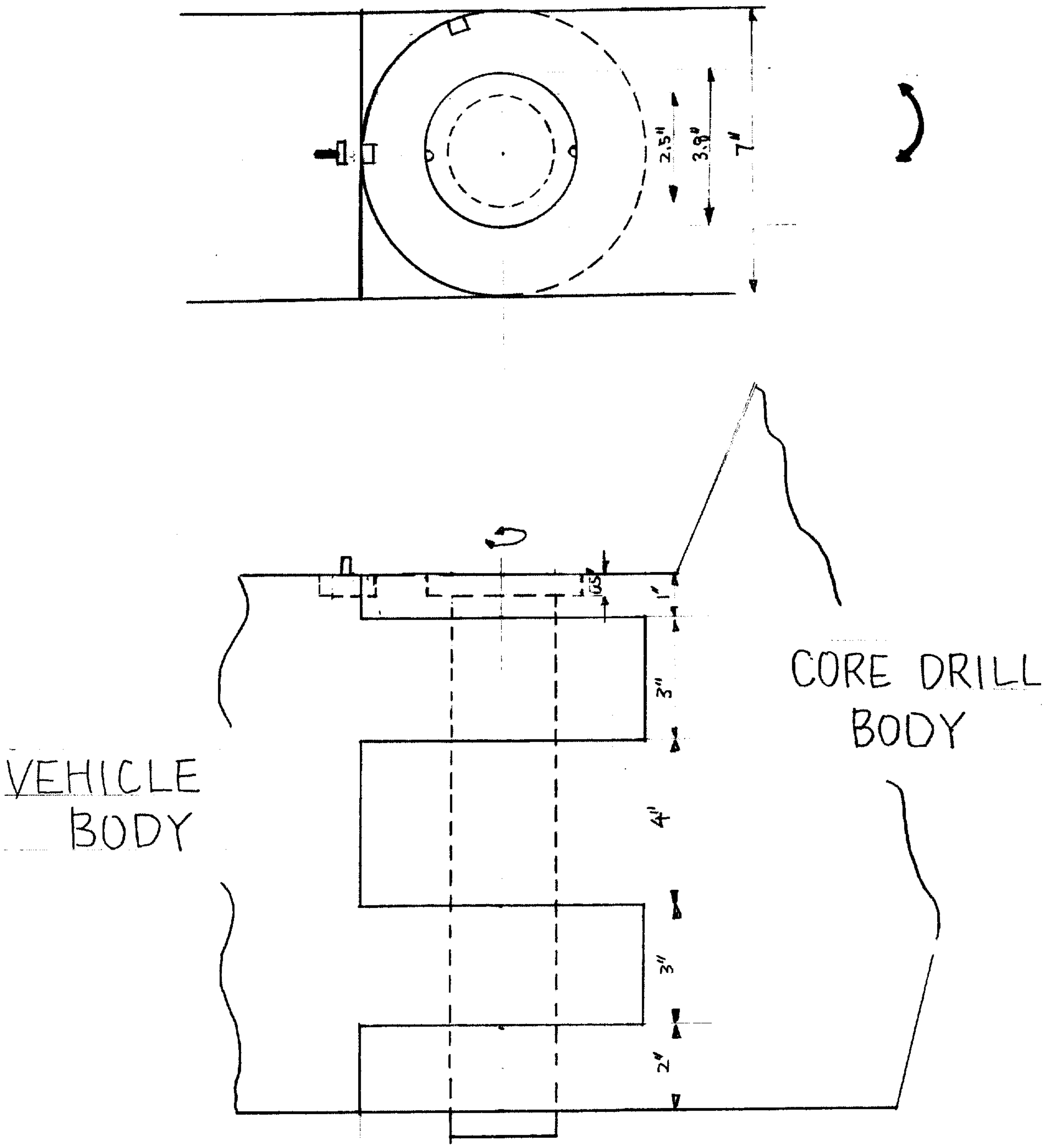
TITLE: Clip Bar

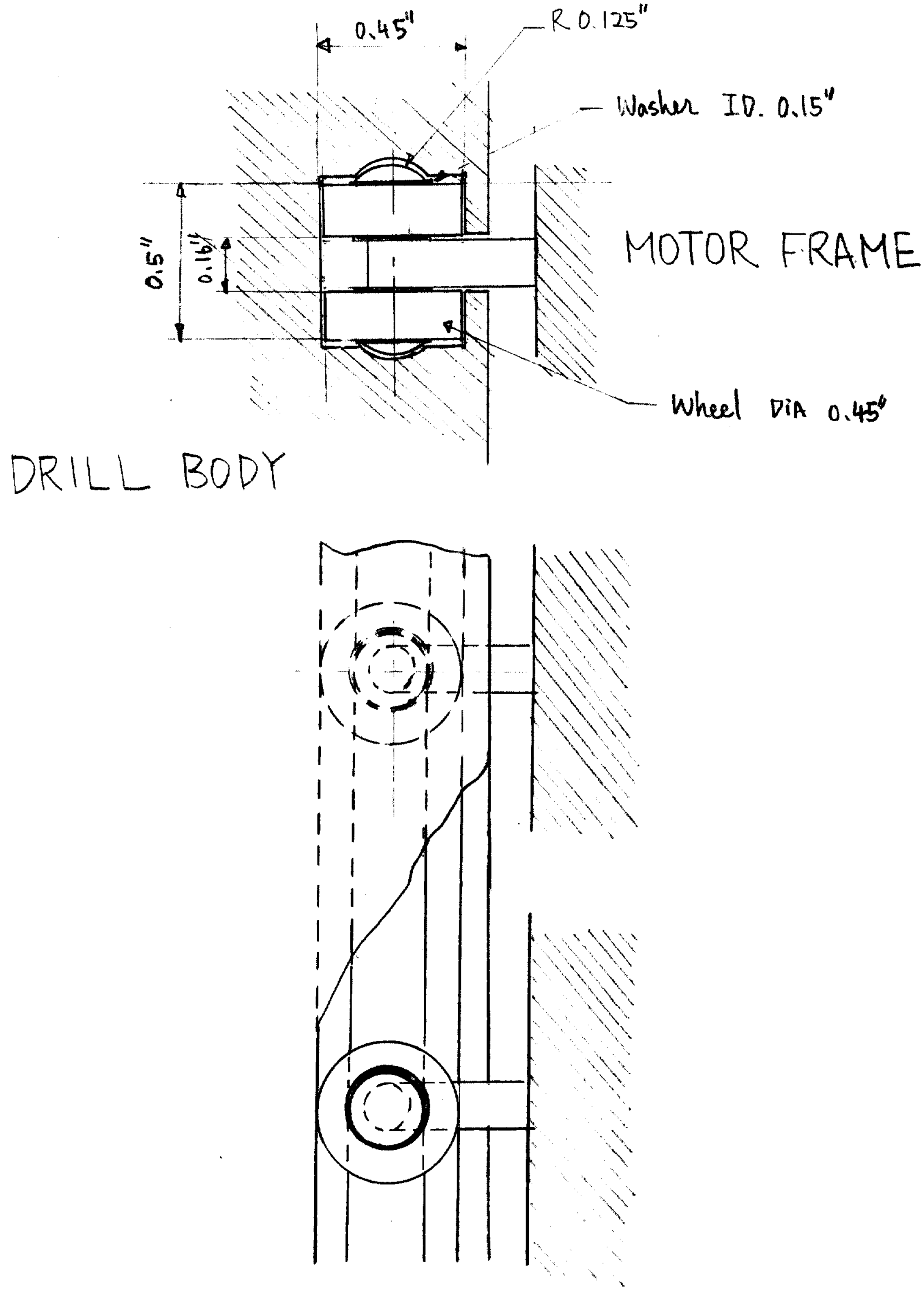
material: 2330 steel

2-4-2

SCALE 1:1



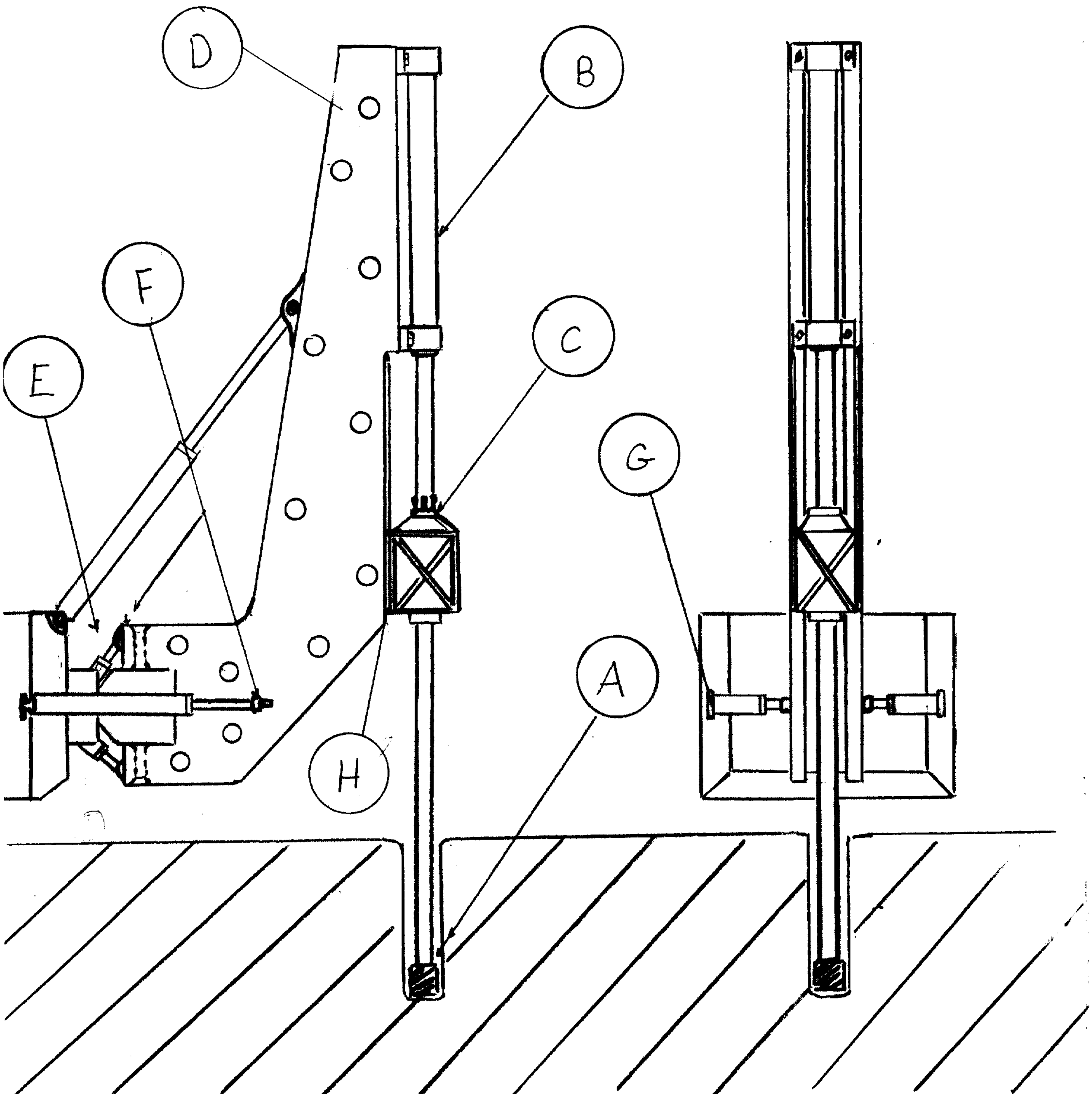
DRAWING NO.: 3-1-1	COMMENTS
TITLE: IMPLEMENT INTERFACE	



DRAWING NO: 3-1-2

TITLE: GUIDE TRACK FOR MOTOR MOVEMENT.

COMMENTS

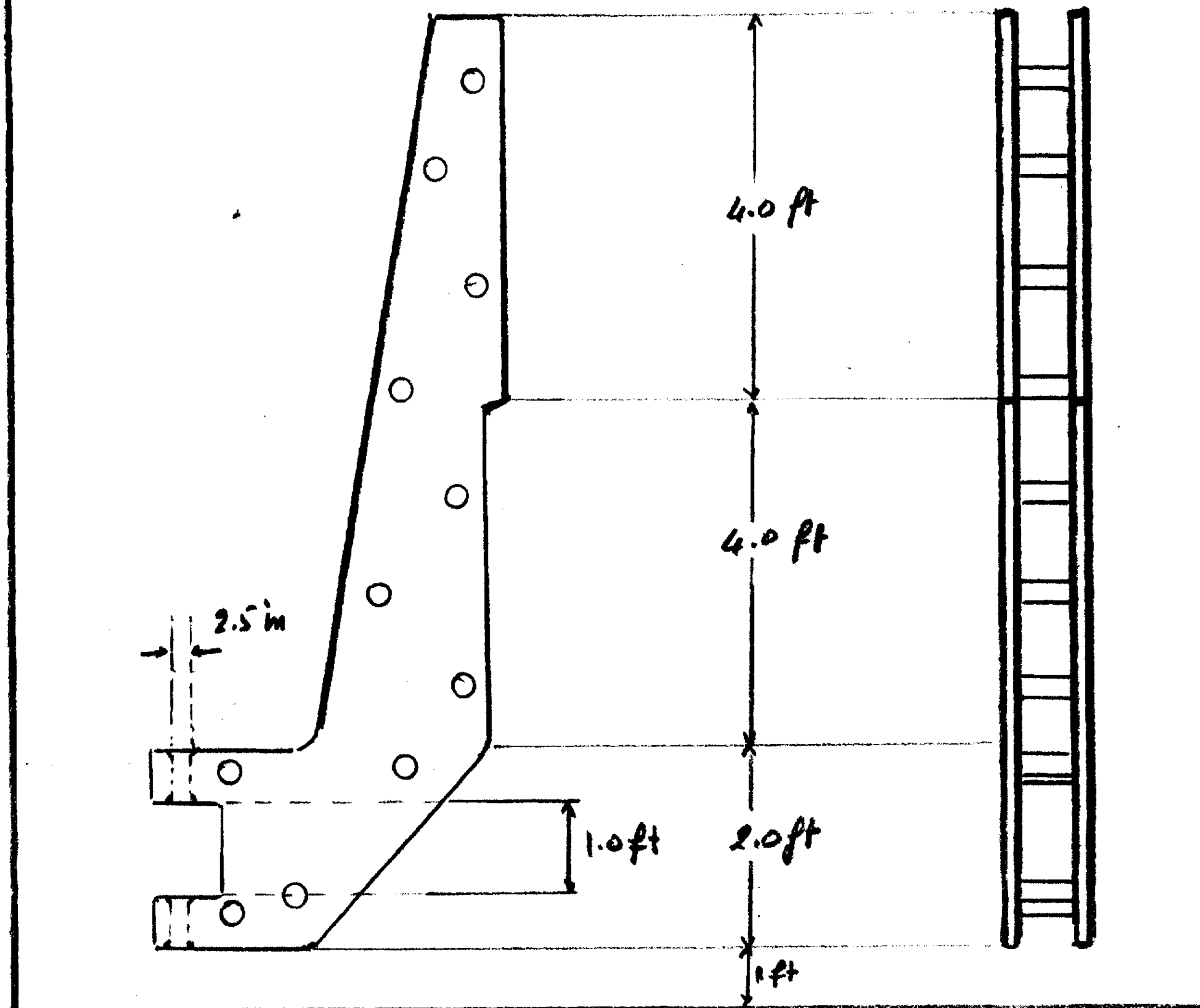


(A) Drawing # 1
(B) Drawing # 2-3
(C) Drawing # 2-4
(D) Drawing # 3-2
(E) Drawing # 3-3
(F) Drawing # 3-4
(G) Drawing # 3-4-1
(H) Drawing # 3-1

MAIN DRAWING OF THE LUNAR CORE DRILL

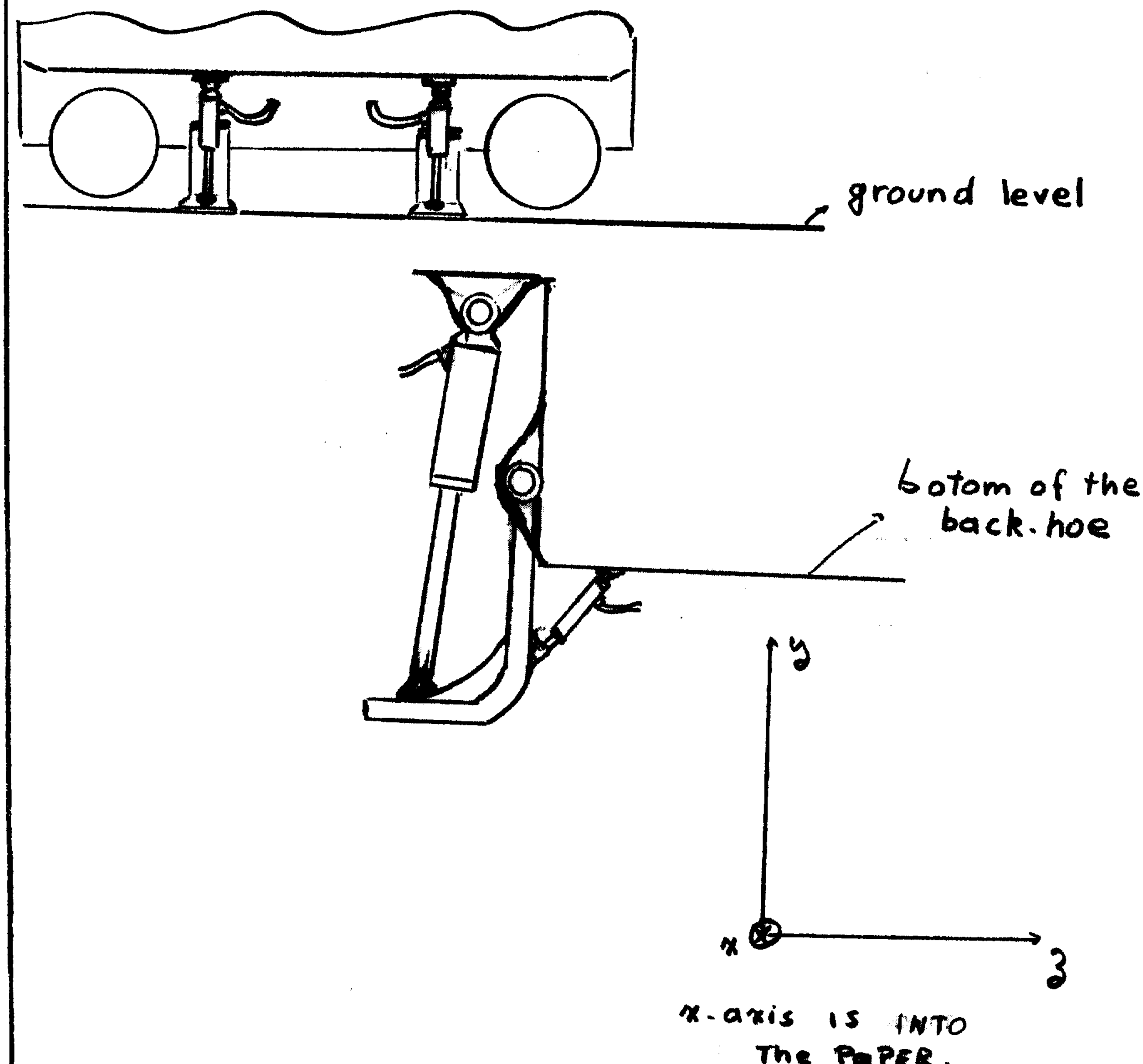
Drawing # 3

SCALE: 1/24



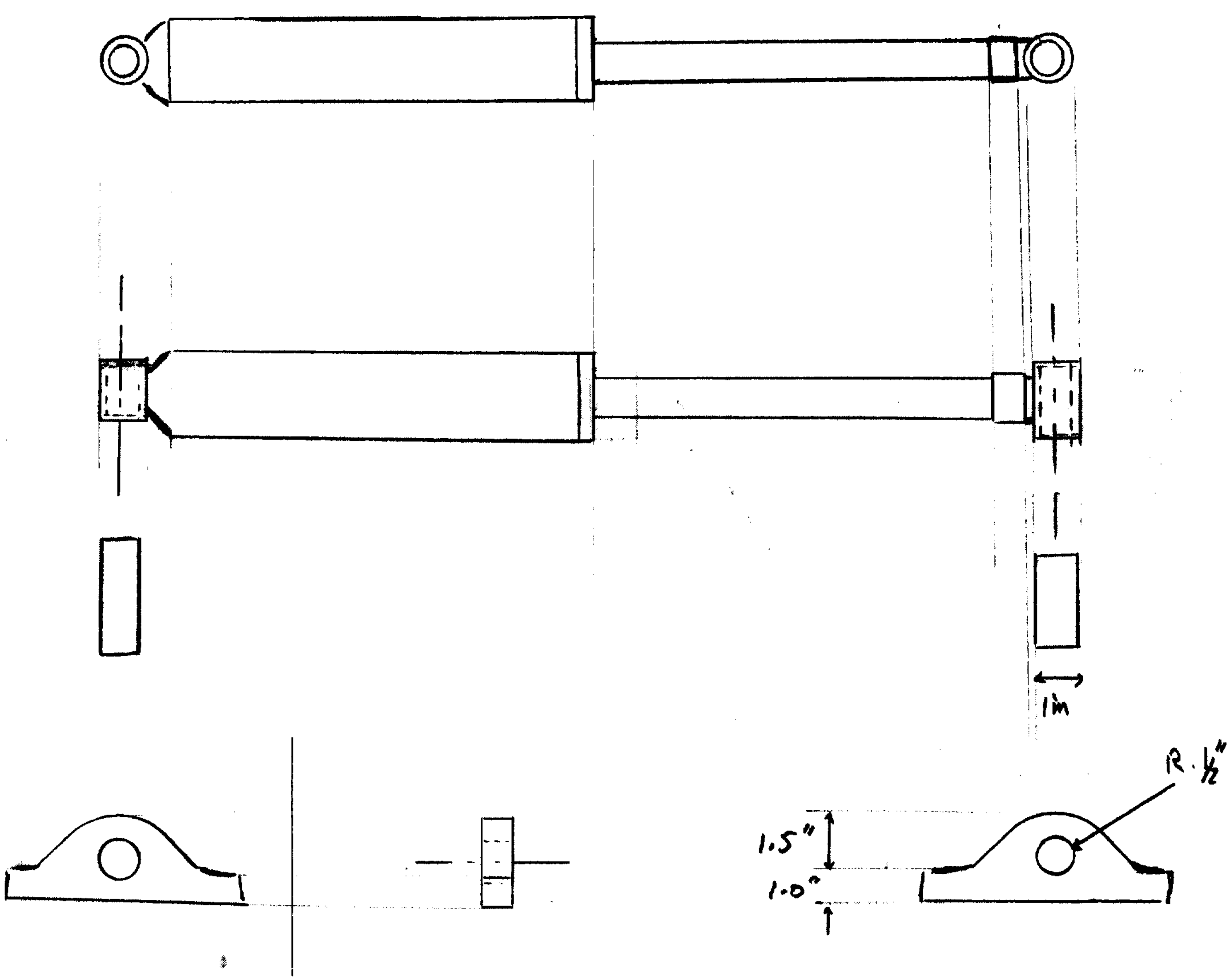
DIMENSIONS & SHAPE OF THE RIG
TO BE MADE OF ALUMINUM TO MINIMIZE
THE WEIGHT

Drawing # 3-2	
SCALE : 1/24	



LEVELING OF THE DRILL ABOUT THE X-AXIS

Drawing # 3-2-1



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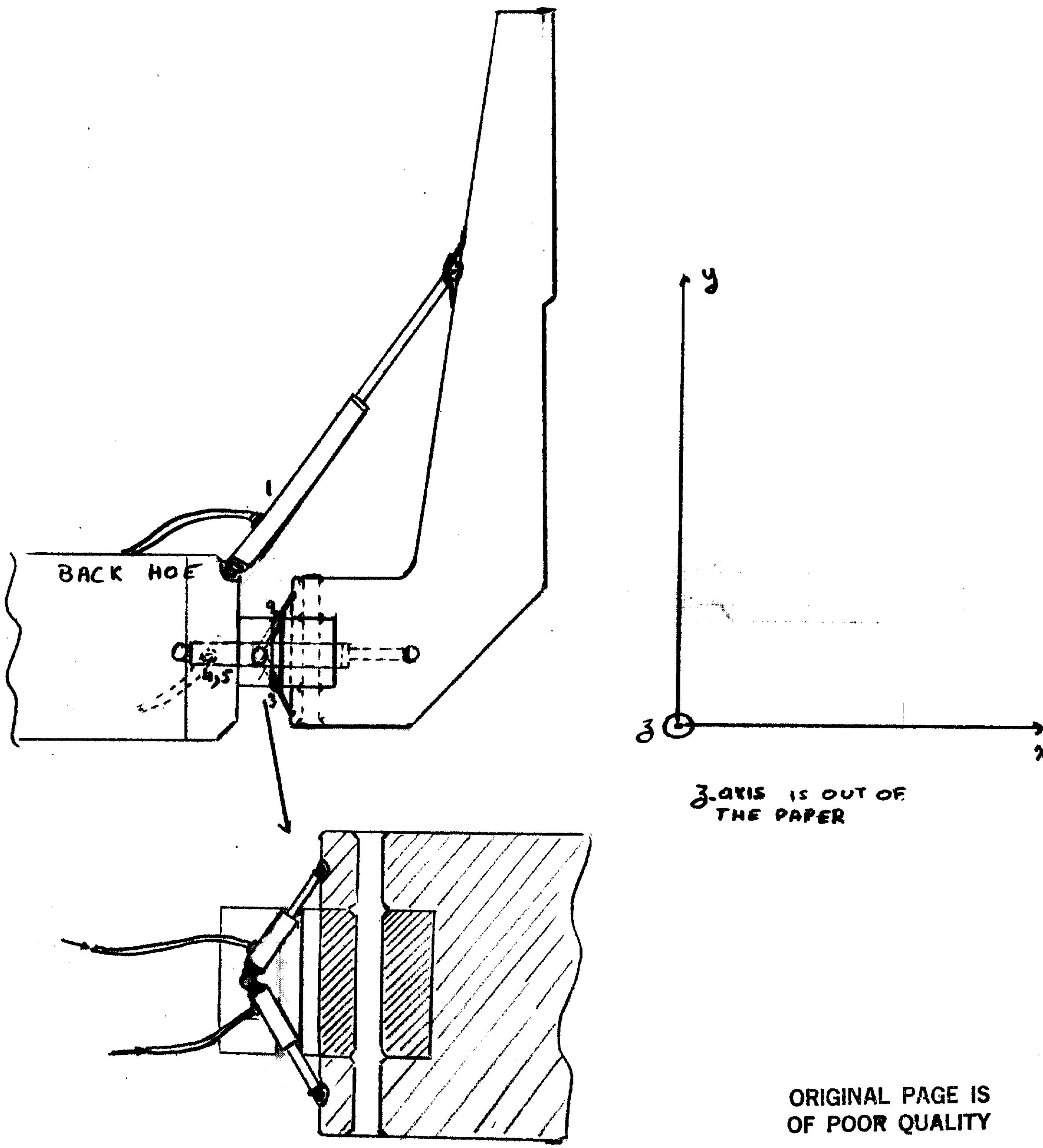
OF POOR QUALITY

SCHEMATIC OF A HYDROLIC CYLINDER
SHOWING THE WAY IT SHOULD BE MOUNTED
ON A BEARING

Drawing #3-2-1A



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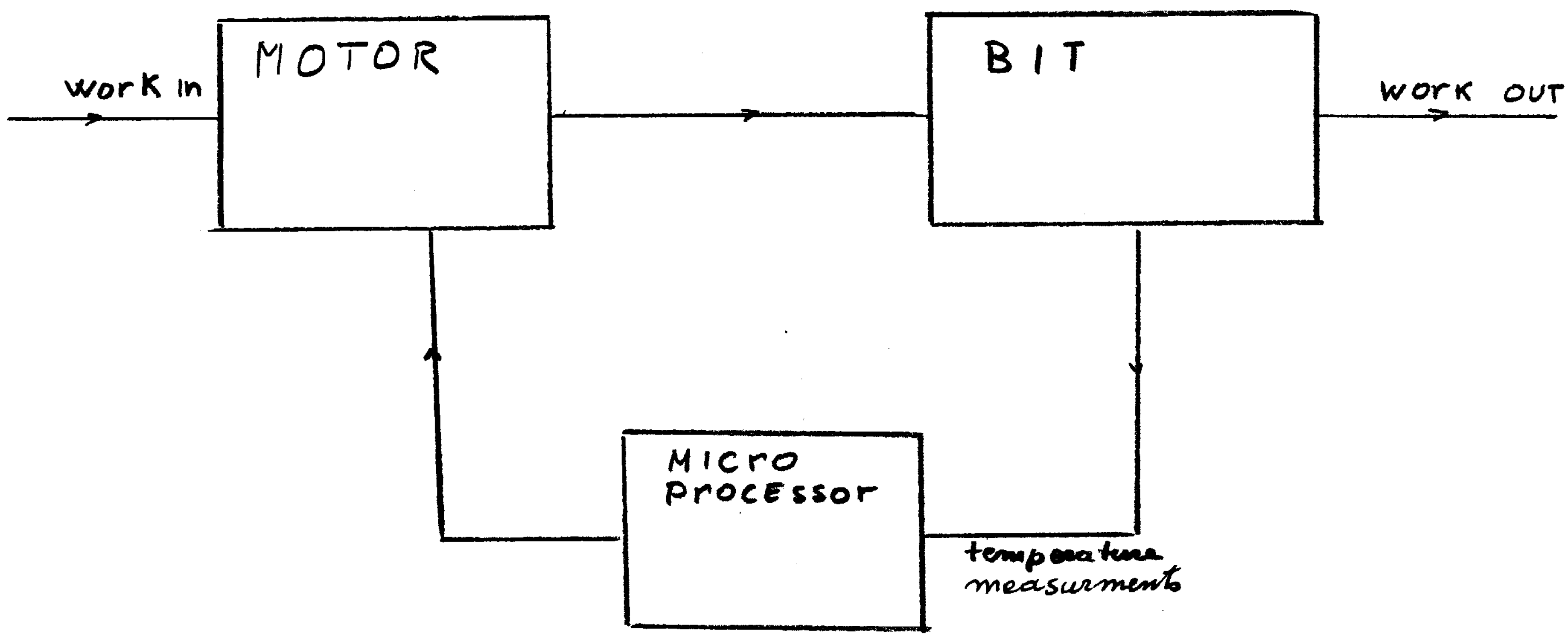
LEVELING MECHANISMS OF THE DRILL ABOUT THE Z & Y AXES.

Drawing 3-4 & 3-4-1

SCALE: 1/24



INFORMATION FLOW DIAGRAM
FOR COOLING THE DRILL BIT

ME 4182 WEEKLY PROGRESS REPORT

PERIOD: Jan. 10, 1985 THRU: Jan. 17, 1985 TEAM NO.: TH 2:30

TITLE: Lunar Coring Drill

COMMENTS:

Team met and devided work up. Each member was occupied with researching present core drills and their operation. Trying to locate information sources is presenting a problem.

NAME, INITIALS	HOURS ENGINEERING	TECHNICIAN	CLERICAL	TOTAL
1) Christopher Thompson	10			10
2) Nabil Khater	10			10
3) Alan Schunk	5			5
4) Jack Kimsey	7			7
5) Jae Lew	6			6
6)				
TOTALS =	38			38

ME 4182 WEEKLY PROGRESS REPORT

PERIOD: Jan. 18, 1985 THRU: Jan. 24, 1985 TEAM NO.: TH 2:30

TITLE: Lunar Coring Drill

COMMENTS:

Met often to compare notes on individual research results. Began researching lunar environment and its possible effects on coring and core drills. Redefined individual duties with respect to core drill components and processes.

	HOURS			
NAME, INITIALS	ENGINEERING	TECHNICIAN	CLERICAL	TOTAL
1) Christopher Thompson	9		0.5	9.5
2) Nabil Khater	8			8
3) Alan Schunk	6			6
4) Jack Kimsey	7			7
5) Jae Lew	11			11
6)				
TOTALS =	41		0.5	41.5

ME 4182 WEEKLY PROGRESS REPORT

PERIOD: Jan. 25, 1985 THRU: Jan. 31, 1985 TEAM NO.: TH 2:30

TITLE: Lunar Coring Drill

COMMENTS:

The team was primarily occupied with locating and studying material pertaining to their own division of technical concern. Preliminary feasibility studies have been made by the group for certain components of the core drill.

NAME, INITIALS	HOURS ENGINEERING	TECHNICIAN	CLERICAL	TOTAL
1) Christopher Thompson	8		1	9
2) Nabil Khqter	8			8
3) Alan Schunk	6			6
4) Jack Kimsey	6			6
5) Jae Lew	7			7
6)				
TOTALS =	35		1	36

ME 4182 WEEKLY PROGRESS REPORT

PERIOD: Feb. 1, 1985 THRU: Feb. 7, 1985 TEAM NO.: TH 2:30

TITLE: Lunar Coring Drill

COMMENTS: Feasibility studies are continuing on components of the core drill. Specification of preformance parameters have been made for the hydrostatic transmission and power system/prime mover. Seals appropriate for lunar operation have been selected. Work is continuing on other phases of the drill.

	NAME, INITIALS	HOURS ENGINEERING	TECHNICIAN	CLERICAL	TOTAL
1)	Christopher Thompson	7			7
2)	Nabil Khoder	5			5
3)	Alan Schunk	5			5
4)	Jack Kimsey	6			6
5)	Jae Lew	7		1	8
6)					
	TOTALS =	30		1	31

ME 4182 WEEKLY PROGRESS REPORT

PERIOD: Feb. 7, 1985 THRU: Feb. 14, 1985 TEAM NO.: TH 2:30

TITLE: Lunar Coring Drill

COMMENTS: This week our group continued to research the different parts of the core drill and discussed its use as an implement for the bulldozer or backhoe.

Our research material included technical reports and VSMF catalogs to find out what machinery is already available.

We also used mathematical formulas to determine the type and design of machinery needed for our particular specifications.

We observed bulldozers and backhoes on campus to consider methods of implementing a core drill to these machines.

NAME, INITIALS	HOURS ENGINEERING	TECHNICIAN	CLERICAL	TOTAL
1) Christopher Thompson	3	3		6
2) Nebil Khater	5			5
3) Alan Schunk	6			6
4) Jack Kimsey	7		0.5	7.5
5) Jae Lew	5			5
6)				
TOTALS =	26	3	0.5	29.5

ME 4182 WEEKLY PROGRESS REPORT

PERIOD: Feb 14, 1985 THRU: Feb 21, 1985 TEAM NO.: TH 2:30

TITLE: Lunar Coring Drill

COMMENTS: This week our group continued its research, created drawings, and made further calculations in the development of the core drill.

Our research efforts included continued use of VSMF vendors and standards, technical reports, and exploring other technologies in which core drilling is used (high vacuum seals for rotating and stationery shafts, ice core drilling).

Also, we have begun to make drawings of the different drill systems (bit, dust removal, frame, hydraulic motor and cylinder) to be prepared to hand them in next week.

Finally, we have done further calculations considering column buckling, hydraulic cylinder size, and dust removal volume.

NAME, INITIALS	HOURS ENGINEERING	TECHNICIAN	CLERICAL	TOTAL
1) Christopher Thompson	5	1		6
2) Nabil Khater	2.5	2.5		5
3) Alan Schunk	5	1		6
4) Jae Lew	4	2		6
5) Jack Kimsey	5	1	0.5	6.5
6)				
TOTALS =	21.5	7.5	0.5	29.5

ME 4182 WEEKLY PROGRESS REPORT

PERIOD: Feb. 22, 1985 THRU: Feb. 28, 1985 TEAM NO.: TH 2:30

TITLE: Lunar Coring Drill

COMMENTS: This week our gruop continued its research, created detailed drawings, and made further calculations in the development of the core drill.

Work has begun on writing the report and learning how to use the Spellstar word processing software.

NAME, INITIALS	HOURS ENGINEERING	TECHNICIAN	CLERICAL	TOTAL
1) Christopher Thompson	2	7	3	12
2) Nabil Khater	3	1	0	4
3) Alan Schunk	4	3	0	7
4) Jae Lew	4	1	0	5
5) Jack Kimsey	6	1	0	7
6)				
TOTALS =	19	13	3	35

ME 4182 WEEKLY PROGRESS REPORT

PERIOD: Feb. 29, 85 THRU: Mar. 7, 85 TEAM NO.: TH 2:30

TITLE: LUNAR CORE DRILL

COMMENTS:

This week we finished our research, but continue to design and draw in detail each part of the core drill. Also, we redrew some of last week's design for the final report. So far, we have completed 20 drawings for the final report.

Each member has started to type his part of the report on a word processor. Later, we will get together and edit the final report.

	NAME, INITIALS	HOURS ENGINEERING	TECHNICIAN	CLERICAL	TOTAL
1)	Thompson, C.		5	5	10
2)	Khater, N.	2	3		5
3)	Schunk, A.	4	8		12
4)	Lew, J.	3	3	3	9
5)	Kimsey, J.	5	9	1	15
6)					
	TOTALS =	14	28	4	51